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VOLUME 33 JULY, 1959 NUMBER 4

PERMIAN ALGAE FROM SAUDI ARABIA

RICHARD REZAK

Shell Development Company, Houston

ABSTRACT—The Khuff formation of Saudi Arabia has yielded an algal flora including: *Gymnocodium bellerophontis* (Rothpletz), *Gymnocodium moniliforme* Pia, *Solenopora centurionis* (Pia), *Mizzia velebitana* (Schubert) *Mizzia bramkampi* n. sp. and *Epimastopora* sp. Well preserved specimens of *Mizzia velebitana* yielded data that require the transfer to the genus to the tribe Diploporeae. The algal assemblage dates the Khuff formation as late middle Permian or late Permian.

INTRODUCTION

THE Khuff algal flora was first called to my attention by Lloyd G. Henbest of the U. S. Geological Survey. Later R. A. Bramkamp, of the Arabian American Oil Co., kindly sent me additional material for study. The collections were made from core samples taken in a well that penetrates limestone of the Khuff formation. The well, Dammam 43, is in the Hasa Province, Dammam area, of the east coast of the Arabian Peninsula. It is located at Lat. 26°20′N and Long. 50°10′E. The samples represent ten horizons at depths of from 8904.8 to 8950.7 feet and four horizons at depths of from 9228.9 to 9234.6 feet. All samples yielded remains of fossil algae; however, the lowest six were thoroughly recrystallized and although algae were recognized it was difficult to distinguish species.

According to Bramkamp (letter dated, 6 October 1957), "the Khuff limestone consists of alternating hard and soft limestones, commonly with shelly limestone layers capping low benches. Considerable dolomitization is present locally. Marls and gypsiferous clays occur in substantial amounts in the upper half of the unit and in thin beds sporadically through the remainder." The thickness, calculated at the type section, is approximately 741 feet.

However, in the subsurface, the formation attains a thickness of about 1650 feet. The samples I have studied are from the upper half of the formation, the uppermost sample being approximately 400 feet below the top of the formation.

Types and figured specimens are in the U. S. Geological Survey Algae Collection, Denver Federal Center, Denver, Colorado.

I wish to thank Dr. R. A. Bramkamp for making this material available to me and for obtaining clearance from the Arabian American Oil Co. to publish the results of this study. Dr. Riuji Endo, Saitama University, Japan, kindly sent me topotype material from Karpinsky's locality near Akasaka, Japan. I am grateful to Dr. Milan Herak, University of Zagreb, Yugoslavia, for sending me topotypes of *Mizzia velebitana* from Schubert's locality in Croatia. Thanks are also due Kenji Konishi for many hours of stimulating discussion concerning upper Paleozoic algae.

Publication is authorized by the Director, U. S. Geological Survey.

SYSTEMATIC PALEONTOLOGY

Division RHODOPHYTA
Class FLORIDEAE
Order NEMALIONALES
Family GYMNOCODIACEAE Elliott 1955
Genus GYMNOCODIUM (Pia) Elliott 1955
Genotype: *Gymnocodium bellerophontis* (Rothpletz) Pia 1920

G. F. Elliott (1955, p. 83–85) has written an account of the systematic position of the genus *Gymnocodium* which need not be repeated here.

However, the identification of species remains a difficult matter. Measurement of the external and internal features of *Gymnocodium* are not very helpful, as the dimensions of these features overlap in several of the established species. Although most authors state the dimensions of their material, the main consideration seems to be difference in general appearance. The table below lists characteristics that have been used by other authors for specific determination. The overlap of these dimensions from one species to another is obvious.

Sporangia are sometimes present in sections of *Gymnocodium* but more often than not they are lacking.

The sporangia may be either spherical or ovoid and may be located either in the cortex or the medulla. At first glance the sporangia seem to furnish a good basis for distinguishing species. However, because of their infrequent occurrence they cannot be used for this purpose. Many collections contain not a single specimen with preserved sporangia. Whether these collections represent only sterile plants or whether they were fertile plants in which the sporangia were lost in the process of fossilization cannot be determined. The presence of two types of sporangia may indicate a specific difference but there is the possibility that they represent two generations within the same species. Some modern Florideae have a biphasic alternation of generations in which the gametophyte (sexual generation) alternates with the carposporophyte (asexual generation).

Another difficulty in identifying species is caused by the random orientation of seg-

TABLE 1—DIMENSIONS USED FOR SPECIFIC IDENTIFICATION BY OTHER AUTHORS

Species	Length	Width	Wall Thickness	Pore Diameter	Sporangia		Age	General Locality
					Location	Size		
G. bellerophontis (Rothpletz)	2.6	1.25	0.15	0.030–0.050	medullary	0.29	late Permian	Central and South Central Europe, Asia
G. texanum Johnson	0.68–1.32	0.44–1.98	0.075–0.46	0.026–0.040	none observed	0.27–0.48	late Permian	Texas
G. japonicum Konishi	4.37–9.30	0.75–1.50	?	0.055–0.084	subcortical		late middle Permian	Japan
G. nodosum Ogilvie Gordon	?	0.65–1.40	0.06	0.082	none observed		late Permian	South Tirol, Northern Italy
G. piai (Endo)	4.5 –5.0	3.8 –4.0	0.324–0.326	0.041–0.073	none observed		Permian	Japan
G. compressum Pia	no data						late Permian	South Tirol
G. moniliforme Pia	no data						late Permian	Hungary
G. canum Pia	no data						late Permian	Yugoslavia

Measurements in mm.

ments in a thin section. Sections coinciding with the long axis of a segment are easily recognized by the presence of axial openings at the base and apex of the segment. Sections normal to the long axis are generally circular. However, oblique sections through cylindrical segments are more difficult to recognize because they often resemble sections through tapering segments. Segments that exhibit pinching and swelling may actually represent pinching and swelling of the thallus or they may represent sections through deformed cylinders. The shapes of the peripheral filaments in such sections change from rodlike in the axial sections to circular in the tangential sections.

For the purpose of this paper, I have distinguished only two species. Plants with spheroidal segments are referred to *G. moniliforme* Pia and those with cylindroidal or pinching and swelling segments to *G. bellerophontis* (Rothpletz).

GYMNOCODIUM MONILIFORME Pia
Pl. 71, figs. 1,14

"birnformige Alge," JABLONSZKY, 1918, Foldt. Kozl., v. 48, p. 450.
Gymnocodium moniliforme PIA, 1937, Congr. Av. Etude Strat. Carb., 2d (Heerlen, 1935), p. 834.

Pia's description of this species, from the Permian series of Bosnia and western Serbia, is very brief and generalized. He refers to Jablonszky's description of pyriform algae with branched canals and states that it is similar to *G. fragile*. Both have rounded, often almost spherical segments. The major difference is in the size of the sporangia and the degree of calcification. No dimensions are given by Pia for either species. His illustrations of *G. fragile* show the sporangia to be cortical.

The Saudi Arabian material is spherical to pear-shaped. The range of dimensions in mm. of four specimens is as follows:

Length	1.30–1.80
Width	0.93–1.20
Wall thickness	0.10–0.25
Pore diameter	0.35–0.40
Sporangia	
Size	0.18–0.28 wide. Only one specimen contained complete sporangia 0.28×0.42
Location	—Subcortical to medullary
Shape	—Ovoid

Rao & Varma (1953, p. 21) described spherical forms from the Punjab Salt Range as *G. piai*. Their species has been transferred to the genus *Permocalculus* by Elliott (1955, p. 86).

GYMNOCODIUM BELLEROPHONTIS (Rothpletz) Pia 1920
Pl. 71, figs. 2,4,5,7–9,11–13,16

Gyroporella bellerophontis ROTHPLETZ, 1894, Stuttgart, p. 24, fig. 4.
Gymnocodium bellerophontis PIA, 1920a, Zool.-bot. Gesell, Wien, Abh., v. 11, pt. 2, p. 34; 1920b, Ann. Nat. Mus. Wien, v. 33, p.3,7–9, 13,16.

In his review of the genus *Gymnocodium*, Elliott (1955) transferred many species having pore diameters less than 0.030 mm. to his newly established genus *Permocalculus*. The remaining species, with pore diameters greater than 0.030, were retained in the genus *Gymnocodium*. Elliott's specimens of *G. bellerophontis* from Iraq have pore diameters of 0.030 to 0.050 mm. The range in pore diameters of the Saudi Arabian specimens is identical. The table below lists the range of dimensions in mm. from fifteen specimens of *G. bellerophontis*.

Length	1.00–4.00	
Width	0.55–1.30	
Wall thickness	0.12–0.30	
Pore diameter	0.30–0.50	
Sporangia		
Size	0.10–0.14	0.18–0.23
Location	cortical	medullary
Shape	spheroidal	ovoid

GYMNOCODIUM sp.
Pl. 71, figs. 6,10

Many fragments of *Gymnocodium* not identifiable to species are present in the samples of Khuff formation. The specimens are difficult to identify either because of poor preservation or because of their orientation in the thin sections. For example, tangential sections that do not intersect the medulla do not show enough features for proper identification.

Pl. 71, fig. 6 is an illustration of a poorly preserved specimen which exhibits a tridentate outline of a segment. To my knowledge, this form has not previously been reported for *Gymnocodium*. The segment very closely resembles some of the tridentate segments of *Halimeda opuntia* Lam. This resemblance, although noteworthy, is not considered sufficient to warrant consideration

of a relationship between *Gymnocodium* and *Halimeda*.

Order CRYPTONEMIALES
Family SOLENOPORACEAE
Genus SOLENOPORA Dybovsky
Genotype *Solenopora spongioides* Dybovsky 1879
SOLENOPORA CENTURIONIS (Pia Johnson 1942
Pl. 71, fig. 15

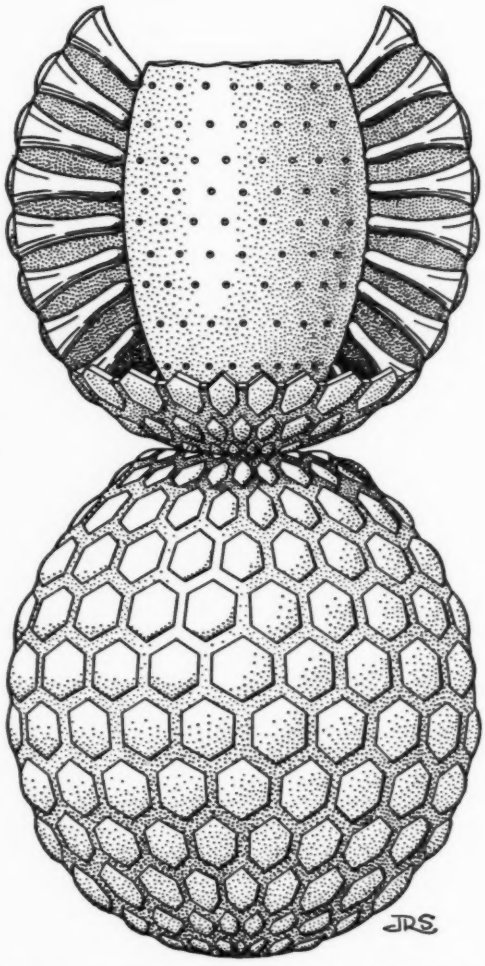
Solenopora centurionis PIA, 1940, Akad. Wiss. Wien, Anz., Jahrg. 1940, no. 9, p. 57; JOHNSON, 1942, Geol. Soc. America, Bull., v. 53, p. 200, pl. 1, figs. 1,3–6. ——, 1951, Jour. Paleontology, v. 25, p. 22, pl. 1, figs. 1–3.

The thallus is lobate, 2.2 mm. high and 2.7 mm. wide. Cells are 0.035–0.060 mm. wide in longitudinal section. Wall thickness is 0.012 mm. No transverse partitions are visible in longitudinal section. The dimensions of the one specimen referred to this species fall within the range given by Johnson in 1942.

Division CHLOROPHYCOPHYTA
Class CHLOROPHYCEAE
Order DASYCLADALES
Family DASYCLADACEAE
Tribe DIPLOPOREAE
Genus MIZZIA (Schubert) emend. Rezak
Genotype *Mizzia velebitana* Schubert 1908.

Mizzia SCHUBERT, 1907, K. k. geol. Reichsanstalt, verhandl. Wien, no. 8, p. 212.
Mizzia velebitana SCHUBERT, 1908, K. k. geol. Reichsanstalt, Wien. Jahrb., Bd. 58, p. 382, pl. 16, figs. 8–12.

Emended generic diagnosis.—The thallus is composed of segments joined end to end in a loosely articulated fashion. The segments are generally disaggregated and are rarely found joined together like a string of beads. Individual segments are spheroidal to cylindroidal or pyriform and are composed of a central cavity (generally barrel-shaped) through which the stipe extended. Radiating from the central cavity are simple expanding, unbranched rays arranged in regular, alternating horizontal rows. At the periphery of the segment the expanded rays are in mutual contact. The alternating nature of the rays and their crowding at the periphery gives rise to a hexagonal (honeycomb) pattern on the surface of each segment (see Text-fig. 1). Species are based upon shapes and dimensions of the segments and their internal structures.



TEXT-FIG. 1—Schematic diagram of *Mizzia velebitana* (Schubert). ×20. Upper segment cut away to show stipe and arrangement of rays. Lower segment complete to show honeycomb pattern of ray extremities on outer surface.

A comprehensive list of the literature concerning the genus *Mizzia* has been presented by Johnson & Dorr (1942). However, there are certain discrepancies between the original descriptions and illustrations of the genus and later interpretations that warrant further scrutiny of a few of the generic characteristics. Johnson & Dorr recognized some of these discrepancies but because of a misunderstanding of Karpinsky's statements (1908) regarding the morphology of *Mizzia* they made no attempt at revision of the genus.

Schubert in his descriptions of the genus

remarked on its close resemblance to the Silurian genera *Coelosphaeridium* Roemer and *Apidium* Stolley. These statements apparently influenced Pia's interpretation of the genus more than other contradictory evidence presented both by Schubert and Karpinsky. As early as 1912, Pia (1912, p. 56) had assigned the genus *Mizzia* to the Cyclocrinidae (changed to the Tribe Cyclocrineae by Pia in 1927) which includes the two Silurian genera. The Tribe Cyclocrineae is characterized by simple, expanding rays (*Wirteläste*) irregularly disposed on the stipe (*Stammzell*). Pia (1920a, p. 20), in describing the species *Mizzia velebitana*, stated incorrectly that the rays are without a recognizable orderly arrangement.

In his first description of *Mizzia*, Schubert (1907, p. 212) did not refer to the arrangement of the rays. He referred only to their irregular expansion toward the outer surface. Later (1908, p. 383) Schubert is a somewhat more detailed description, stated: "ausstrahlenden primären Wirteläste waren schlauchförmig mit unregelmäszig wechselnden Lumen basal erweitert und mündeten mit polyedrischemhexagonalem Querschnitte an der Oberfläche aus." I assume that Schubert meant by his phrase "unregelmäszig wechselnden Lumen" that the lumens were irregularly alternating, that is, not disposed one above the other in regular rows.

Karpinsky (1908, p. 260) on the basis of much better preserved material described the species *Mizza japonica* as having relatively regularly arranged rays which lie in four alternating, horizontal rows. This regular arrangement is certainly evident in his illustrations of *M. japonica* and *M. velebitana*. Examination of topotype material of *M. velebitana* and *M. japonica* from Yugoslavia and Japan substantiates this regular arrangement of the rays. Johnson & Dorr (1942, p. 73) state that "In many, if not most of the specimens from the southwestern U. S., the branches (or the protuberances representing their termination at the outer surface) appear to be arranged in roughly regular alternating rows, resembling a honeycomb pattern." Pl. 72, figures 8 and 9, and Text-figure 1 of the present paper show this honeycomb pattern very well.

Perhaps one of the reasons that this honeycomb pattern has not been observed by some workers is that in most specimens the pattern does not become apparent until after treatment with water or glycerine. This is well illustrated by figures 9 and 12 of Pl. 72. The specimen in figure 9 was coated with glycerine prior to being photographed. The same specimen is shown in Text-figure 12 but this photograph was taken before the specimen was coated with glycerine. Text-figure 12 shows no evidence whatsoever of the honeycomb pattern.

Near the end of his paper, Karpinsky (1908, p. 268) makes the statement that *Mizzia* is closest to the group of Triassic siphoneae to which *Gyroporella* Gümbel and *Physoporella* Steinmann belong. The rediscovery of regularly arranged rays in the genus *Mizzia* requires that the genus be transferred from the Cyclocrineae to the Tribe Diploporeae to which the Triassic genera mentioned by Karpinsky belong. This has been accomplished in the present paper.

Pia (1920a, p. 21) speculated on the form of the thallus of *Mizzia*. He was the first to recognize that the spheroidal to pyriform bodies were united to form a segmented thallus with the stipe passing through each segment. He believed that as no segments were ever found that possessed two openings at one end, the thallus must have been unbranched. He also commented on the absence of distal segments which he considered should be closed at the apex because the stipe should not extend beyond the apex of the plant.

A brief comparison between *Mizzia* and its modern counterpart *Cymopolia* shows that Pia's statements are not necessarily valid. *Cymopolia* is a dasyclad which has a segmented, dichotomously branched, thallus. No Y-shaped segments are present at the dichotomies in *Cymopolia*. Instead, three individual segments make up each dichotomy. These segments are not fused even in the older parts of the thallus. The absence of branched segments in *Mizzia* does not mean that the thallus was unbranched.

In *Cymopolia*, the stipe extends through and beyond the apical segment of each branch. Growth of the thallus is by addition of new segments which surround the part of the stipe extending beyond tips of the branches. It is doubtful that apically closed terminal segments of *Mizzia*, such as Pia suggests, will ever be found.

On the basis of this comparison it seems natural to assume that, in life, the thallus of *Mizzia* was quite similar to that of the modern *Cymopolia*. However, until more nearly complete thalli of *Mizzia* are found, this concept of its form is purely speculative.

MIZZA VELEBITANA (Schubert)
emend. Rezak
Pl. 72, figs. 1–3,5,6,8–10,12,13,15–19

Mizzia SCHUBERT, 1907, K. k. geol. Reichsanstalt, verhandl. Wien, no. 8, p. 212.

Mizzia velebitana SCHUBERT, 1908, K. k. geol. Reichsanstalt, Wien, Jahrb., Bd. 58, p. 382, pl. 16, figs. 8–12; KARPINSKY, 1908, Russ. Kaiserl. Min. Gezell, Verhandl., ser. 2, f. 46, p. 262, pl. 3, figs. 6–9; PIA, 1920a, Zool. botan. Gesell. Wien, Abh., Bd. 11, h. 2, p. 19, pl. 1, figs. 12–23; OZAWA, 1925, Tokyo Imp. Univ. Fac. Sci. Jour., Sec. 2, v. 45, fasc. 6, p. 5, pl. 1, figs. 1a,2a, pl. 2, figs. 6b,7c; PIA, 1937, 2d Cong. Strat. Carbonif. Heerlen 1935, Compte Rendu, p. 765, pl. 6, fig. 3; ——, 1940, Akad. Wiss. Wien, Math.-natur. kl. Auz. no. 9, p. 55; MAKHAEV, 1940, Biull. Mosk. obshch, ispit. prirody, otd. geol., v. 8, pl. 1, figs. 1–3,11; JOHNSON & DORR, 1942, Jour. Paleontology, v. 16, p. 71–73, pl. 9, figs. 1–3, pl. 10, figs. 2,3,5, pl. 11, figs. 1,2; JOHNSON, 1942, Geol. Soc. America Bull., v. 53, p. 203, pl. 2, figs. 1,2,4, pl. 3, figs. 1–3; ——, 1951, Jour. Paleontology, v. 25, p. 23, pl. 7, figs. 1–4; ENDO, 1952a, Trans. Proc. Paleont. Soc. Japan, N.S., No. 5, p. 141, pl. 12, fig. 5; KONISHI, 1952, Trans. Proc. Paleont. Soc. Japan, N.S., No. 5, p. 157, pl. 14, figs. 11,12; ENDO, 1952b, Saitama Univ., Sci. Repts., v. 1, p. 25, pl. 1, fig. 2; ——, 1953, Japan Jour. Geol. and Geog., Trans., v. 23, p. 120, pl. 11, figs. 1,2; KONISHI, 1954b, Japan Jour. Geol. and Geo., v. 25, p. 4; ——, 1954a, Jour. Fac. Sci. Univ. Tokyo, Sec. 2, v. 9, pt. 2, p. 228, pl. 1, fig. 9; ENDO & KANUMA, 1954, Saitama Univ., Sci. Repts., Ser. B, v. 1, p. 192, pl. 14, figs. 8,9; ENDO & HASHIMOTO, 1955, Proc. Japan Acad., v. 31, no. 10, p. 707, fig. 2; ——, 1956, Saitama Univ., Sci. Repts., v. 2, p. 227, pl. 22, figs. 3–8; ——, 1957, Saitama Univ., Sci. Repts., v. 2, p. 283, pl. 37, figs. 4,5, pl. 44, fig. 3.

Johnson & Dorr (1942, p. 71–72) have already listed the measurements of this species by its author and other workers. Subsequent descriptions have been examined and the following emended diagnosis is a synthesis of previous descriptions and new information derived from the present study.

Emended diagnosis.—The segments are spheroidal to pyriform, 0.72–2.4 mm. long and 0.6–2.9 mm. wide having a central cavity from 0.3–1.9 mm. in diameter. The rays are simple cylinders or expanding cylindroids 0.07–0.36 mm. in greatest diameter, arranged in alternating horizontal rows, 20 to 25 rays in each row.

Measurements in mm. of specimens from the Khuff formation are as follows:

Length of segment	1.29–1.60
Diameter of segment	1.06–1.80
Diameter of central cavity	0.51–1.20
Primary branches	
Shape	cylindrical
No. in whorl	22–24
Diameter	0.09–0.18

MIZZIA BRAMKAMPI Rezak, n. sp.
Pl. 72, figs. 4,14

Diagnosis.—The segments are spheroidal, 0.7 to 1.0 mm. in diameter. The central cavity is 0.46 to 0.60 mm. in diameter. The rays are funnel shaped, maintaining a diameter of 0.09 mm. for about one half the distance to the outer surface and then rapidly expanding to a diameter of 0.23 mm. The number of rays in a whorl varies from 13 to 15.

Remarks.—This species is distinguished from others by the funnel-shaped rays and the fewer number of rays per whorl. It is named for R. A. Bramkamp, who made available the material described in this paper.

Holotype.—USGS a144b2.

Genus EPIMASTOPORA Pia, 1922
EPIMASTOPORA sp.
Pl. 72, figs. 7,11.

Specimens representing this genus are very abundant in the upper part of the Khuff formation. These specimens are generally quite long and curved fragments of thalli. Wall thicknesses range from 0.156 to 0.175 mm. Rays are apparently cylindrical and range from 0.034–0.052 mm. in diameter.

The species of this genus are so poorly known that it was considered inadvisable to attempt specific identification on the basis of these fragments.

AGE OF THE KHUFF FORMATION

The Khuff formation has been considered to be of Permian age. A degree of uncertainty has been attached to this age assignment because it lies unconformably on lower Paleozoic rocks at the type section. Bramkamp states (personal communication, 1957), "So far the only diagnostic fossils found there (on the outcrop) have been a few poor nautiloids and brachiopods (which

also fit a Permian age). . . . Aside from the rare nautiloids, fossils are not uncommon but they are almost exclusively small, nondescript lamellibranchs and gastropods. In a few places some very poor brachiopods reminiscent of *Derbyia* occur."

Henbest (report to R. A. Bramkamp, dated 26 July, 1957), regarding the foraminifera of the Khuff, states:

> "This porous, coquinoid limestone has been dolomitized and the preservation of the microfossils is so poor that, excepting the algae, most genera are recognizable with some uncertainty. Your supposition that the rock is upper Paleozoic is supported by the microfossils. Permian is indicated with fair assurance. According to the present, rather meager knowledge of the range of *Colaniella prisca?* (Colani) the lower part of the upper Permian is indicated, but question even of Permian versus Pennsylvanian age must remain until this evidence is verified with other information."

The Khuff algal flora described here is almost identical to the flora of the "Bellerophon-zone" of the upper Permian in southern Europe. The association of *Mizzia velebitana* and *Gymnocodium bellerophontis* is common throughout the Tethian province from southern Europe eastward to Iraq, Iran, the Caucasus, Saudi Arabia, the Pamir of southern Russia, the East Indies, and Japan. The occurrences of *Mizzia* in this province are listed by Johnson & Dorr (1942, p. 66–67) along with the faunas with which it is associated. These faunas indicate an age range of late middle through late Permian although most occurrences are in the zones of *Neoschwagerina* and *Yabeina*. Unfortunately, the fusulinids in the Khuff formation are quite thoroughly recrystallized and in most cases not identifiable.

The present state of knowledge concerning the fossil algae indicates that the part of the Khuff formation containing these fossils is certainly Permian and probably late middle or upper Permian in age.

ENVIRONMENTAL SIGNIFICANCE OF THE ALGAE

The presence of abundant Dasycladaceae in the Khuff formation indicates that the beds containing these fossils were deposited in a very shallow, warm, marine environment.

Table 2 shows the distribution of the various algae with depth of sample in the well. The genus *Gymnocodium* is represented in samples from all depths but the genus *Mizzia* is restricted to two samples and occurs abundantly in only one. There is an inverse relationship between the presence of *Gymnocodium* and *Epimastopora*. One possible

TABLE 2. DISTRIBUTION OF SPECIES IN DAMMAM 43 WELL

USGS Paleobotanical Locality	Field No.	Depth in feet	*Gymnocodium* sp.	*G. bellerophontis*	*G. moniliforme*	*Mizzia velebitana*	*Mizzia bramkampi*	*Solenopora centurionis*	*Epimastopora* sp.
D644	PSX-1	8904.8–8904.9	R						X
D645	PSX-2	8905.8	R	X					X
D646	PSX-3	8906.3–8906.6	R						R
D647	PSX-4	8906.9–8907.2	X	X				R	R
D648	PSX-5	8919.1–8919.3	X	X	X	R			R
D649	PSX-6	8920.9–8921.1	X	X	R				
D650	PSX-7	8931.9–8932.2	X						
D651	PSX-8	8933.9–8934.1	X	X	X	X	X		
D652	PSX-9	8934.9–8935.1	X	X					
D653	PSX-10	8950.6–8950.7	X	X	X				
D654	PSX-11	9228.9–9229.2	X			Badly recrystallized			
D655	PSX-12	9229.8–9230.0	X	X					
D656	PSX-13	9230.8–9231.1	X						
D657	PSX-14	9234.4–9234.6	X	X					

X = common. R = rare.

interpretation of this relationship is a gradual shoaling of water in which *Gymnocodium* alone was originally growing until a depth was reached which would support a lush growth of both *Gymnocodium* and *Mizzia*. As the shoaling continued both *Mizzia* and *Gymnocodium* were replaced by *Epimastopora*. Depth zonation of a similar nature has been observed among the modern algae.

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EXPLANATION OF PLATE 71

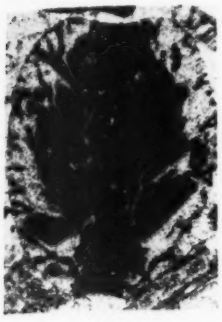
FIGS. *1,14—Gymnocodium moniliforme* Pia. *1,* (USGS a149d1) Loc. D648, axial section showing basal and apical perforations and possible sporangia near base of segment, note few preserved axial filaments and branched cortical filaments, ×25; *14,* (USGS a152d1) Loc. D651, broken axial section showing three ovoid, medullary sporangia in lower half, ×25.

2,4,5,7–9,11–13,16—Gymnocodium bellerophontis (Rothpletz). *2,* (USGS a149f1) Loc. D648, nearly axial section showing one segment within another. How this happened is not known. Circular dark areas on left side of outer cortex are cortical sporangia, ×25; *4,* (USGS a150d1) Loc. D649, oblique section showing circular cross sections of cortical filaments at base and conical longitudinal sections at top, ×25; *5,* (USGS a154d2) Loc. D653, longitudinal section of segment showing subcortical sporangium on right side, ×25; *7,* (USGS a144a1) Loc. D651, longitudinal section showing pinching and swelling of segment, ×25; *8,* (USGS a144a2) Loc. D651, nearly longitudinal section, note suggestion of branched cortical filaments on left side, ×25; *9,* (USGS a152b3) Loc D651, longitudinal section of a broken segment showing pinching and swelling, ×25; *11,* (USS a144a3) Loc. 651, oblique section, left side tangential right side nearly longitudinal, ×25; *12,* (USGS a148c1) D647, longitudinal section showing well preserved medullary filaments, ×12½; *13,* (USGS a148f1) Loc. 647, longitudinal section of a very long segment, ×7½, *16,* (USGS a154c2) Loc. D653, nearly longitudinal section showing simple expanding cortical filaments.

3—Gymnocodium aff. *G. moniliforme* Pia. (USGS a152e1) Loc. D651, transverse section scalloped inner surface of cortex on left side probably caused by medullary sporangia, ×25.

6,10—Gymnocodium sp. *6,* (USGS a154c1) Loc. D653, tridentate segment very similar to some segments of the present-day green alga *Halimeda,* ×25; *10,* (USGS a148b1) Loc. D647, tangential section showing arrangement of cortical filaments, ×25.

15—Solenopora centurionis Pia. (USGS a148e1) Loc. D647, lobate colony growing on a shell fragment, ×12½.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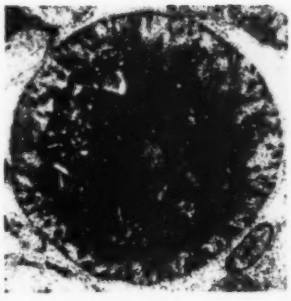
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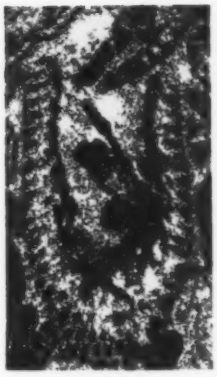
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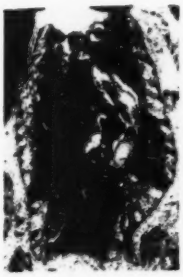
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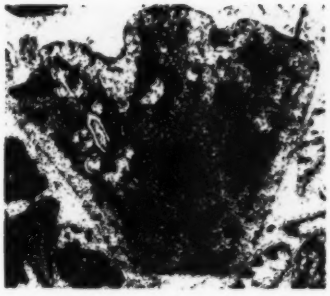
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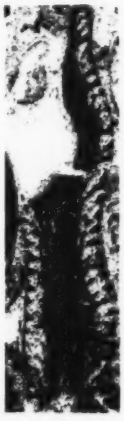
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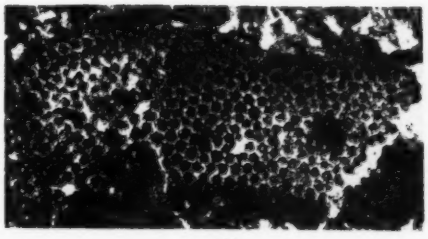
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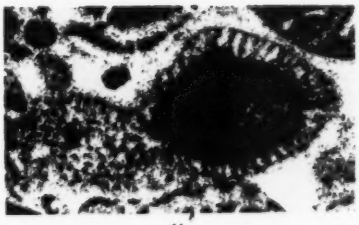
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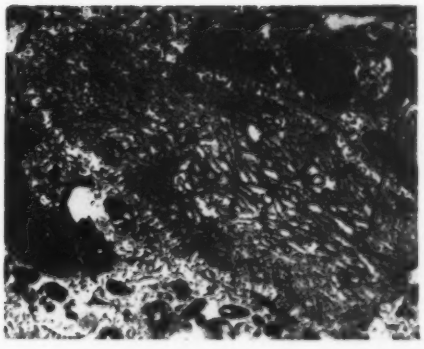
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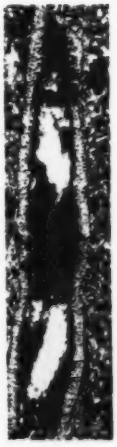
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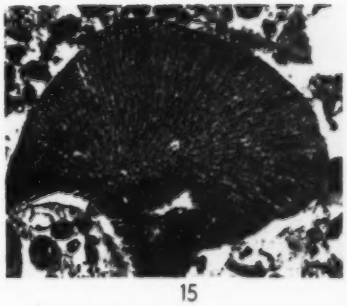
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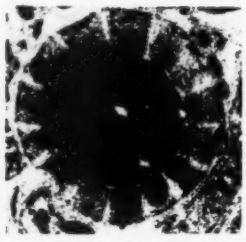
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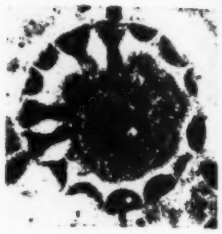
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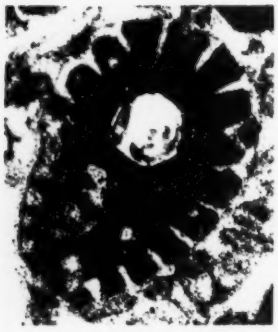
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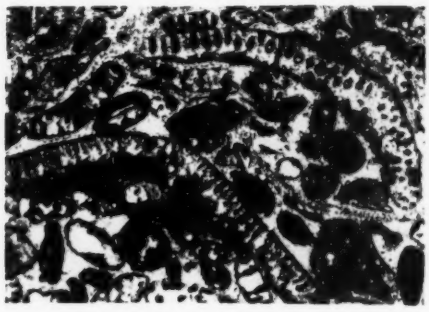
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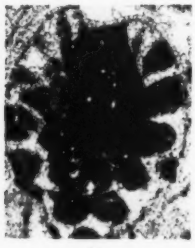
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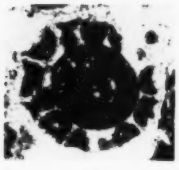
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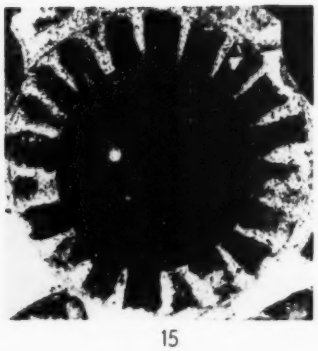
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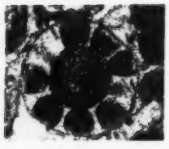
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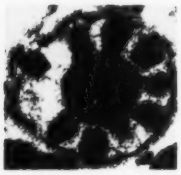
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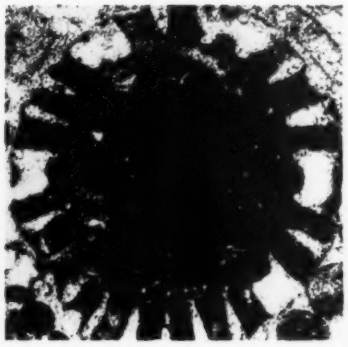
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EXPLANATION OF PLATE 72

FIGS. *1–3,5,6,8–10,12,13,15–19—Mizzia velebitana* (Schubert). *1*, (USGS a152e2) Loc. D651, nearly axial section showing apical perforation and nearly cylindrical rays, ×25; *2*, (USGS a144a4) Loc. D651, oblique section through poorly preserved specimen, ×25; *3*, (USGS a144d1) Loc D651, transverse section showing cylindrical rays, ×25; *5*, (USGS 144c1) Loc. D651), nearly axial section showing basal perforation and poorly preserved rays, ×25; *6*, (USGS a144a5) Loc. D651, oblique section showing cylindrical and expanding cylindroidal rays, ×25; *8*, (USGS a152f4) Loc. D651, ovoid specimen showing surface of alternating, horizontal rows of rays, ×12½; *9*, (USGS a152f2) Loc. D651, complete pyriform specimen showing "honeycomb" pattern of rays, treated with glycerine, ×12½; *10*, (USGS a144b3) Loc. D651, oblique section passing through one of the axial perforations, notice change in shape of rays according to their orientation in the section, ×25; *12*, same specimen as in figure 9 of this plate, untreated, notice very poor, irregular appearance of rays at surface, ×12½; *13*, (USGS a152f21) Loc. D651, transverse section through a free individual showing cylindrical rays, ×12½; *15*, (USGS a152b5) Loc. D651, transverse section through a large specimen, ×25; *16*, (USGS a144c2) Loc. D651, oblique and tangential sections through two segments, note nearly circular cross sections of rays in both segments, ×25; *17*, (USGS a149g1) Loc. D648, transverse section near base or apex of segment, note rounded cross-sections of rays, ×25; *18*, (USGS a144d2) Loc. D651, transverse section similar to that shown in fig. 17, ×25; *19*, (USGS a152d2) Loc. D651, transverse section through a large specimen, ×25.

4,14—Mizzia bramkampi Rezak, n. sp. *4*, Holotype (USGS a144b2) Loc. D651, oblique section showing chracteristically inflated ray extremities, ×25; *14*, (USGS a144b4) Loc. D651, transverse section near apex or base of segment, ×25.

7,11—Epimastopora sp. *7*, (USGS a145a1) Loc. D644, large, curved fragments of this genus, ×25; *11*, (USGS a145a2) Loc. D644, *Epimastopora* hash, ×25.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 540–546, PL. 73, 1 TEXT-FIG., JULY 1959

ORDOVICIAN CONODONTS FROM NORTHERN MANITOBA

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ABSTRACT—A small collection of conodonts is described from the Shamattawa Limestone at a single locality. These are the first such fossils known from the American Arctic or Subarctic and come from about 59 degrees north latitude, in association with an abundant megafauna. Collectively they are similar to other Upper Ordovician conodonts. Of the 18 identified species, only three are defined as new. One new genus, *Plegagnathus* (type: *P. nelsoni*, n. sp.) is proposed.

ORDOVICIAN rocks have been known from west of Hudson Bay for nearly 90 years. The deposits lie directly on a Precambrian complex, are relatively thin, and are poorly exposed except in a few river valleys. The section along the Nelson River has been described in some detail (Savage & Van Tuyl, 1919). Similar occurrences have been reported along the Churchill and Knife rivers to the north (Miller & Youngquist, 1947, p. 409–410; Caley & Liberty, 1957, p. 216). The Upper Ordovician Shamattawa Limestone contains an abundance of fossils (Parks, 1915; Foerste & Savage, 1927; Miller & Youngquist, 1947). Most of these collections were derived from southwest of Hudson Bay, but others have come from some 125 miles north of Nelson River. Nelson (Caley & Liberty, p. 216) is preparing a comprehensive report on the stratigraphy and paleontology of this general area, including fossils from Knife River.

During the past few years a variety of samples have been prepared in a search for conodont faunas associated with the "Arctic" Ordovician. For the most part, results have been negative; the usual lithology, a massive dolomite, in nonproductive in the majority of cases. For example, Knife River materials placed at our disposal by Professor Samuel J. Nelson, proved to be almost barren as acetic acid residues—although abundantly fossiliferous otherwise. The exception was found in a small collection of slabs given us by Mr. John R. Rohner of the State University of Iowa Museum staff. This conodont-bearing rock was obtained rather incidentally, loose on the surface but not far from extensive exposures of the Shamattawa. The lithology is gray fine-grained silty limestone, with a few brachiopods and solitary corals. Some of the other pieces from the same collection were highly fossiliferous but more silty and contained no conodonts.

In the summer of 1954, at the time Rohner visited the locality near the mouth of Knife River, he was unable to penetrate any great distance upstream through the delta area by boat. Travelling on foot, he encountered large quantities of limestone blocks and selected a few fossiliferous slabs at the following approximate geographic coordinates: 58°55′ north latitude, 94°40′ west longitude. These blocks were presumably derived from some miles upstream near existing falls and rapids where ledges exist. The dolomite beds which have been found in the vicinity of Churchill, about 20 miles to the east, rest directly on quartzite but are probably not the same age as those in the Knife River; Nelson (personal communication) states that most of those near Churchill are Silurian.

Since this discussion was written, Nelson has loaned a manuscript copy of his comprehensive report on the stratigraphic succession of the northern Hudson Bay Lowland. Among other details, he confirms the occurrence of "Shamattawa" equivalent in the Knife River delta area; actual exposures of these beds exist only far upstream on the South Knife. According to his studies, preexisting terms are not appropriate and new formation names are proposed. Nelson's faunal studies give much information on correlation but do not oppose the tentative age assignment made here on conodonts.

As is the usual case in isolated conodonts,

many of the specimens are fragmentary, and they are represented by a minimum of identifiable individuals. From the nature of the collections, this material can scarcely be regarded as representative of the available fauna. However, the following species have been recognized:

Belodina dispansa (Glenister)
B. profunda (Branson & Mehl)
Cordylodus robustus Ethington & Furnish, n. sp.
Cyrtoniodus complicatus Stauffer
Drepanodus homocurvatus Lindström
Eoligonodina richmondensis Branson, Mehl & Branson
Gyrognathus elongata Rhodes
Oulodus rohneri Ethington & Furnish, n. sp.
Ozarkodina concinna Stauffer
Panderodus compressus (Branson & Mehl)
P. gracilis (Branson & Mehl)
P. panderi (Stauffer)
P. robustus (Branson, Mehl & Branson)
Plectodina dilata Stauffer
Plegagnathus nelsoni Ethington & Furnish, n. gen., n. sp.
P. dartoni (Stone & Furnish)
Prioniodina? oregonia Branson, Mehl & Branson
Trichonodella sp.

The associated fossils known from the general vicinity of our collections include a variety of molluscs that are characterized by large nautiloid cephalopods and gastropods. The genera *Armenoceras*, *Lambeoceras*, and *Winnipegoceras* have been found in strata of comparable age at a number of localities, Arctic to Rocky Mountains. One of the best known areas is near Winnipeg, some 500 miles to the south. The molluscan-coral fauna of the Selkirk Limestone member of the Red River Formation appears to be closely allied. Conodonts with a faunal aspect similar to that of the Shamattawa have been found in the Grunn Member of the Stony Mountain Formation, overlying the Selkirk. Otherwise, one of the nearest Upper Ordovician localities to Knife River is at Coral Harbour, Southhampton Island, about 500 miles northeast. A sample of limestone from there yielded no conodonts.

In the Knife River collection being studied, a single well preserved specimen of the coral genus *Bighornia* was found; Duncan (1957, p. 611) had reported its occurrence in the Shamattawa. This distinctive slipper-shaped coral is apparently an index genus for Upper Ordovician and is particularly abundant in the Stony Mountain and the Wyoming upper Bighorn.

In our conodont collections from Knife River, *Panderodus* is the most common element and exceeds all the remainder by at least three times. This genus is of relatively little stratigraphic significance, but such abundance characterizes Upper Ordovician in North America. Several of the other identified species are represented in our material by one or two specimens only. *Belodina* is relatively common and the species fairly distinctive. *B. profunda* (B. & M.) is known from the Maquoketa Shale of Missouri, upper Bighorn Shale of Wyoming, and the Stony Mountain Shale of southern Manitoba. A related form, *B. dispansa* (Glenister) has been recorded in the Maquoketa and upper Galena formations of Iowa and the upper Bighorn. *Plegagnathus*, n. gen., has otherwise been observed only in the upper Bighorn and the Stony Mountain. *Cordylodus robustus*, n. sp., has been found also in the Stony Mountain. *Eoligonodina richmondensis* B., M. & B. is known only from Kentucky, but closely related forms occur in the upper Galena and upper Bighorn. *Gyrognathus elongata* Rhodes, originally described from the upper Caradocian, is known from the Galena and upper Bighorn. The other species seem to have little stratigraphic significance. The apparent absence of such characteristic genera as *Amorphognathus* and *Ambalodus* is of doubtful importance in this case.

As an entity, the Shamattawa conodonts are very closely similar to those already known; collectively they verify the generally accepted Cincinnatian age assignment. A correlation with upper Red River-Stony Mountain and upper Bighorn seems justified. Beyond that, the exact stage of type eastern Ordovician is not clear. It is believed, however, that conodonts may be able to contribute as much to our eventual understanding as any group of fossils.

ACKNOWLEDGMENTS

We are grateful to John R. Rohner for providing the material upon which this report is based. Samuel J. Nelson gave advice

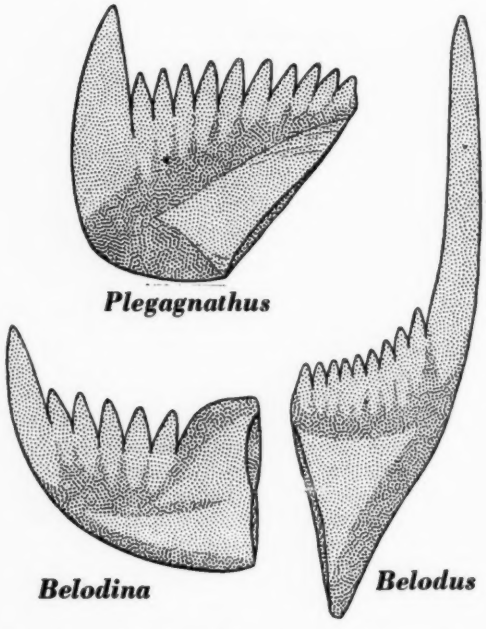
and sent rock specimens from the same area for examination. Edward I. Leith assisted with a study of the section in southern Manitoba for comparison. A. K. Miller offered advice and assistance. The illustrations are pencil drawings by Allan G. Blizzard and Marvin Klaven, prepared from camera-lucida outlines. All type slides are deposited at the State University of Iowa. Fay's 1952 "Catalogue of conodonts" (Kans. Univ. Paleont. Contr., Vert., art. 3) has been employed for synonymies, prior to 1949.

SYSTEMATIC PALEONTOLOGY

Genus BELODINA Ethington, 1959
Type species: *Belodus grandis* Stauffer, 1935

BELODINA DISPANSA (Glenister)
Pl. 73, figs. 12,13

Belodus dispansus GLENISTER, 1957, Jour. Paleontology, v. 31, p. 729–730, pl. 88, figs. 14,15.
Belodina aff. B. *dispansa* ETHINGTON, 1959, ibid., v. 33, p. 272, pl. 40, fig. 15.



TEXT-FIG. *1*—Laterally compressed conodont genera with closely set denticles on posterior margin of cusp. The diagrammatic figure of *Belodus* is after Pander.

Belodina dispansa STONE & FURNISH, 1959, ibid., v. 33, p. 220, pl. 31, fig. 11.

Remarks.—Three specimens resemble the types described by Glenister but do not have lateral striations. The Knife River material is less well preserved than the types from the Maquoketa of Iowa, and the faint striae observed on the latter may have been obliterated in the case of the Canadian specimens. The distal part of the cusp has been lost on all specimens, but it appears to have been long and slender.

Repository.—Figured hypotypes, S.U.I. 10055, 10056.

BELODINA PROFUNDA (Branson & Mehl)
Pl. 73, fig. 5

Belodus profundus BRANSON & MEHL, 1933, Univ. Mo. Studies, v. 8, p. 125, pl. 10, fig. 25; FAY, 1952, Univ. Kans. Paleont. Contr., Vert., art. 3, p. 67 (synonymy).
Belodina profunda STONE & FURNISH, 1959, Jour. Paleontology, v. 33, p. 221, pl. 31, figs. 16,17.

Remarks.—Two specimens are close to *B. profunda* in the development of a high base which is markedly flared on the inner side. Aboral edge of the cusp is sharp; lateral faces are convex and each bears a low, longitudinal costa extending posteriorly from the tip of the cusp to the base of the most anterior denticle. Two stout denticles having convex lateral faces with sharp anterior and posterior edges are set deeply into the oral edge and closely crowded between the vertical extension of the base of the unit and the distal half of the cusp. The expanded base of the unit is excavated by a deep conical cavity which extends anteriorly and bifurcates beneath the posterior oral denticle to form two small terminal cones.

Specimens from the Bighorn of Wyoming which Stone & Furnish referred to this species have either two or three denticles. The Bighorn material exhibits a variation in degree of aboral curvature intermediate between that shown by the type from the Maquoketa of northeastern Missouri and the pronounced recurved lower edge of the northern Manitoba forms.

Repository.—Figured hypotype, S.U.I. 10058.

Genus CORDYLODUS Pander, 1856
Type species: *C. angulatus* Pander, 1856

By definition, this genus includes deeply excavated units having several small denticles rising from the concave posterior edge of the cusp. Some authors consider *Cyrtoniodus*, *Subcordylodus*, *Plectodina*, and *Barbarodina* to be junior synonyms of *Cordylodus*. Sweet (1955, p. 252–253) discussed the relationship of these genera and concluded that a distinction can be made. The type of *Cordylodus* has the denticles rising from the oral surface of a sheathed basal cavity, whereas each of the other four genera possesses a distinct posterior denticulate bar.

CORDYLODUS ROBUSTUS Ethington & Furnish, n. sp.
Pl. 73, fig. 11

Stout complex dental unit consisting of a cusp, distally erect and curving posteriorly toward the base. The oral edge of the base is horizontal in position and forms a right angle with the distal portion of the cusp. The posterior face of the cusp is flat from the point of maximum curvature to the tip and bears a faint median carina. Anterior face of the cusp is broadly rounded. The oral edge of the base is set with eight discrete peglike denticles whose size progressively increases slightly away from the cusp to the sixth denticle; the two posterior teeth are the smallest. Base is flared laterally and deeply excavated.

Remarks.—Only a single specimen was found in the Knife River material. A somewhat smaller specimen was recovered from the shale member of the Stony Mountain Formation near Stony Mountain, Manitoba.

Repository.—Figured holotype, S.U.I. 10059.

Genus EOLIGONODINA Branson, Mehl & Branson, 1951
Type species: *E. robusta* B., M. & B., 1951

EOLIGONODINA RICHMONDENSIS Branson, Mehl & Branson
Pl. 73, fig. 1

Eoligonodina richmondensis BRANSON, MEHL & BRANSON, 1951, Jour. Paleontology, v. 25, p. 15, pl. 4, figs. 23–27.

Remarks.—A single specimen agrees closely to the authors' description of the species.

Repository.—Figured hypotype, S.U.I. 10060.

Genus GYROGNATHUS Stauffer, 1935
Type species: *G. primus* Stauffer, 1935

GYROGNATHUS ELONGATA Rhodes
Pl. 73, fig. 14

Gyrognathus elongatus RHODES, 1953, Roy. Soc. London, Philos. Trans., ser. B., v. 237, p. 318–319, pl. 22, figs. 201,202,205,206; ETHINGTON, 1959, Jour. Paleontology, v. 33, p. 279, pl. 40, fig. 13; STONE & FURNISH, 1959, ibid., v. 33, p. 223, pl. 32, fig. 9.

Remarks.—A single fragmentary specimen is referred to this species. The apical denticle is slender, slightly twisted, with sharp lateral edges and convex anterior and posterior faces. At its base, the first denticle on one lateral bar is equal in width to the apical denticle. The three denticles preserved on the other lateral bar are only half as wide as the apical denticle and are closely crowded. Lateral bars diverge at an angle of 30° beneath the apical denticle. The unit is flared posteriorly at their juncture to accommodate a deep conical basal cavity. The specimen compares closely to forms from the Galena Formation in the Upper Mississippi Valley.

Repository.—Figured hypotype, S.U.I. 10061.

Genus OULODUS Branson & Mehl, 1933
Type species: *O. mediocris* Branson & Mehl, 1933

Forms having a twisted, arched, denticulate bar with a large apical denticle and laterally expanded, excavated aboral surface belong here. It may be that *Gyrognathus* Stauffer is a junior synonym of *Oulodus*, but Rhodes (1953, p. 318) retained the former genus for those forms which resemble *Oulodus* but are laterally compressed aborally.

The type species of *Oulodus* was described from the Plattin of Missouri. A questionable form has been reported from the Kimms-

wick, and a single Richmond specimen was figured by Branson, Mehl & Branson (1951, pl. 3, fig. 19).

OULODUS ROHNERI Ethington & Furnish, n. sp.
Pl. 73, figs. 17,18

Complex asymmetrical dental unit consisting of a twisted arched bar with a large, sharp-edged apical denticle having broadly convex lateral faces. The portion of the bar anterior to the apical denticle is short, inclined sharply downward, and bears two slender subparallel denticles, the first of which is fused to the edge of the apical denticle. The longer posterior segment of the bar is laterally twisted and bears sharp-edged, laterally compressed, closely crowded denticles. The bar is laterally expanded aborally. Pronounced aboral expansion froms a marked lateral flare on one side beneath the apical denticle. A deep basal groove extends along the entire length of the bar, widening beneath the apical denticle.

Repository.—Figured holotype, S.U.I. 10062; figured paratype, S.U.I. 10063.

Genus PLECTODINA Stauffer 1935
Type species: *P. dilata* Stauffer, 1935
PLECTODINA DILATA Stauffer
Pl. 73, fig. 10

Plectodina dilata STAUFFER, 1935, Geol. Soc. America, Bull., v. 46, p. 152,160, pl. 11, figs. 43,47; FAY, 1952, Univ. Kans. Paleont. Contr., Vert., art. 3, p. 147 (synonymy).

Remarks.—A robust specimen is referred to this species. The cusp is broken just above the point of origin of the posterior bar so that the keels in Stauffer's diagnosis can not be observed. However the nature of the denticulation and the configuration of the specimen conform closely in all other respects to the generic description.

Repository.—Figured hypotype, S.U.I. 10064.

Genus PLEGAGNATHUS Ethington & Furnish, n. gen.
Type species: *P. nelsoni*, n. sp.

Plegagnathus is proposed for laterally compressed complex dental units having a cusp, posterior denticulate bar, and aboral process. The unit is deeply excavated by a thin-walled cavity which opens posteriorly and tapers to a sharp point beneath the cusp.

Remarks.—This genus lacks the orally expanded base immediately posterior to the denticles which is typical of *Belodina*. It has a single large basal cavity and is smooth laterally, in contrast to the double cavity and costate or striated faces which characterize the latter genus. *Plegagnathus* has a definite posterior bar bearing denticles which serves to distinguish this form from *Cordylodus* whose denticles rise from the oral margin of the base (Sweet, 1955, p. 252–253). Both *Subcordylodus* and *Barbarodina* possess a posterior bar and erect cusp. The basal cavity in both these genera is restricted to the base of the cusp and continued only as a groove beneath the posterior bar. The cusp of these forms is continued aborally only as an anticusp as opposed to the curved aboral process of *Plegagnathus*.

PLEGAGNATHUS NELSONI Ethington & Furnish, n. sp.
Pl. 73, figs. 2,3

Complex dental unit has an erect cusp, denticulate posterior bar, and an aboral process at right angle to the axis of the cusp. Unit is laterally compressed with regularly curved anterior margin. The aboral process is considered to be horizontal in position. Posterior bar is inclined anteriorly and forms an angle of 45°–60° with the aboral process. Outer lateral face of unit is gently convex, inner face concave. Oral surface of posterior bar set with long, slender denticles which are fused along their edges throughout the greater part of their length. Direction of growth is parallel to the cusp. A deep, thin-walled cavity penetrates anteriorly into the unit with the sharp tip beneath the cusp.

Remarks.—Only the two figured specimens were recovered from the Knife River material. The same distinctive form occurs in a conodont fauna obtained from the shale member of the Stony Mountain Formation near Stony Mountain, Manitoba.

Repository.—Figured holotype, S.U.I. 10065; figured paratype, S.U.I. 10066.

PLEGAGNATHUS DARTONI (Stone & Furnish)
Pl. 73, figs. 6,7

Belodina dartoni STONE & FURNISH, 1959, Jour. Paleontology, v. 33, p. 220, pl. 31, fig. 15.

Each of the three specimens assigned to this species has a stout, erect cusp followed by a series of basally crowded, erect denticles. The denticles, ranging in number from 9-12, are arranged along and penetrate deeply into the oral edge of the unit. They are approximately half as long as the cusp. Outer face of the unit is slightly convex, the inner face is concave. Anterior edge approximates an arc of a circle. The base is deeply excavated by a cavity which penetrates anteriorly into the unit to the base of the cusp.

Remarks.—The specimens described here are more nearly complete than the types of the species but less well preserved. They agree closely with the described Bighorn forms and provide additional information regarding the denticulation of the species. This form lacks the aboral expansion of the base posterior to the denticles which characterizes *Belodina*. Lateral faces are unornamented. The base of the cusp gives off an aboral process and posterior bar which are mutally connected by lateral sheath lamellae. In *Belodina* the cusp is continued posteriorly as a basal cone bearing denticles on its oral surface. The basal cavity of *P. dartoni* is not bifurcated distally.

Repository.—Figured hypotypes, S.U.I. 10067, 10068.

Genus PRIONIODINA Ulrich & Bassler, 1926
Types species: *P. subcurvata* Ulrich & Bassler, 1926
PRIONIODINA? OREGONIA Branson, Mehl & Branson
Pl. 73, fig. 15

Prioniodina oregonia BRANSON, MEHL & BRANSON, 1951, Jour. Paleontology, v. 25, p. 15–16, pl. 4, figs. 28–32.

Remarks.—A single complete specimen and several fragments conform to the figured Richmond forms. These are atypical of *Prioniodina* which is defined as having subparallel, rounded denticles. The general configuration of the Knife River specimens is suggestive of material from the Decorah of Minnesota which Stauffer (1935, pl. 71, figs. 29,31) figured as *Gyrognathus primus*.

Repository.—Figured specimen, S.U.I. 10069.

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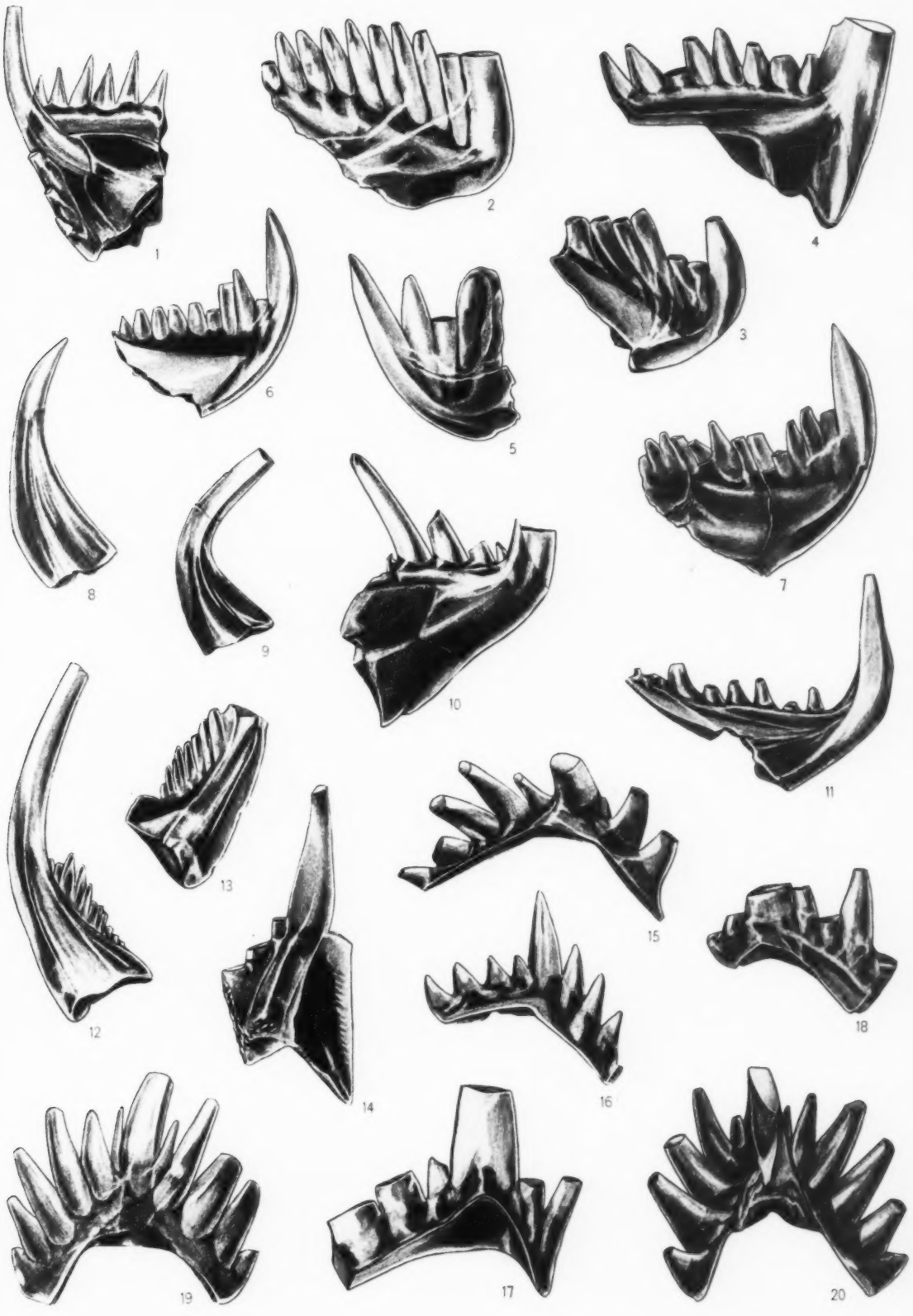
EXPLANATION OF PLATE 73

All specimens figured are from the Shamattawa Limestone, Knife River Delta, Manitoba

FIG. *1*—*Eoligonodina richmondensis* Branson, Mehl & Branson; ×60.
2,3—*Plegagnathus nelsoni* Ethington & Furnish, n. gen.. n. sp.; ×80.
4—*Cyrtoniodus complicatus* Stauffer; ×60.
5—*Belodina profunda* (Branson & Mehl); ×80.
6,7—*Plegagnathus dartoni* (Stone & Furnish); ×60.
8—*Panderodus compressus* (Branson & Mehl); ×40.
9—*Panderodus panderi* (Stauffer); ×40.
10—*Plectodina dilata* Stauffer; ×35.
11—*Cordylodus robustus* Ethington & Furnish, n. sp.; ×35.
12,13—*Belodina dispansa* (Glenister); ×60.
14—*Gyrognathus elongata* Rhodes; ×80.
15—*Prioniodina? oregonia* Branson, Mehl & Branson; ×50.
16—*Ozarkodina concinna* Stauffer; ×80.
17,18—*Oulodus rohneri* Ethington & Furnish, n. sp.; ×60.
19,20—*Trichonodella* sp.; two views ×80.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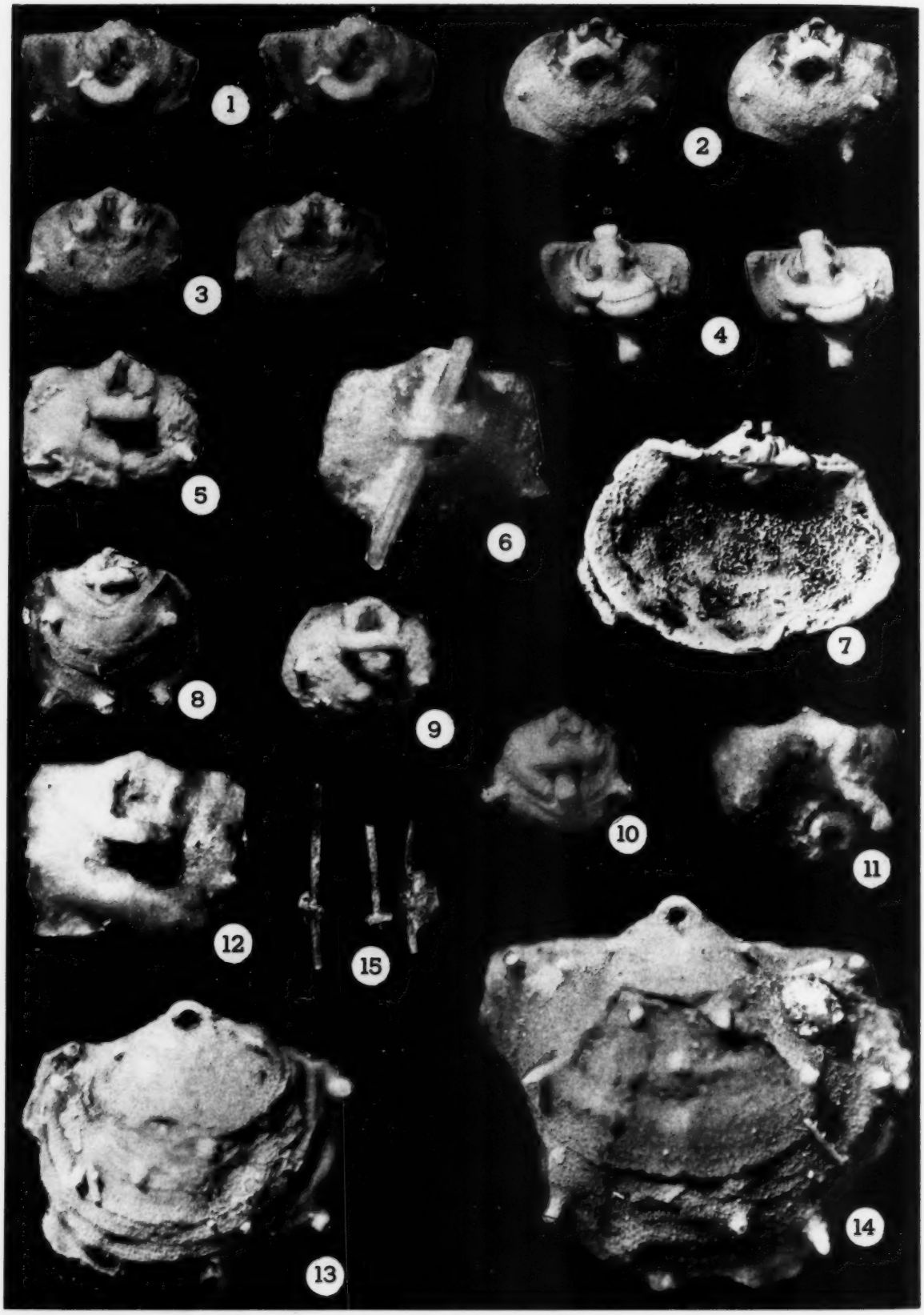
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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 547–549, PL. 74, JULY 1959

ATTACHMENT LOOPS ON INFANT BRACHIOPODS FROM THE LOUISIANA LIMESTONE IN MISSOURI

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ABSTRACT—Shaly partings in the Louisiana limestone in northeastern Missouri contain many small brachiopods. Some of these have been described as *Strophalosia* and *Leptalosia*. Recently discovered ones, however, appear to belong to neither of these genera but are infantile representatives of the genus *Productella*. The pedicle valve of these minute forms bears a loop formed by the upward curving growth of a pair of spines on opposite sides of a shallow median groove. This loop was apparently used in infant stages as a means of attachment to the spines of adults or to the spines and stems of crinoids. Although larger specimens of *Productella* are spinose, the attachment loops are not present on those larger than 10 mm. in width.

INTRODUCTION

THE shaly layers of the Louisiana limestone in northeastern Missouri contain many minute brachiopods. Some of these were described and illustrated by Williams in his report on the Louisiana limestone fauna (1943). More recently Niewoehner, studying samples for a conodont investigation (1955), discovered many others and they are the basis for the present report. Approximately 500 specimens were recovered. John Koenig of the Missouri Geological Survey also gave us several specimens from the McCraney limestone in Seahorne Hollow, Illinois. Also we are indebted to Dr. G. A. Cooper of the U. S. National Museum for help and encouragement.

PREVIOUS WORK

It has long been known that immature brachiopods may become attached to adult brachiopods or to other substrata. This at-

EXPLANATION OF PLATE 74

All specimens are from the Louisiana limestone. Those in Figures *1,2,3,4,7,8,10,12,13,15* are from Clarksville; those in Figures *5,11* are from Buffalo Hill; those in *6,9,14*, are from Clinton Springs in the southern part of Louisiana.

Approximate magnification: Figures, *7,15* are ×15; *1,2,3,5,8,9,13,14* are ×20; *4,10* are ×25; and *6,11,12* are ×35.

All are pedicle valve views except *7*.

FIG. *1*—Stereo pair of specimen 1.4 mm. wide, showing completely developed loop.

2—Stereo pair of specimen 1.4 mm. wide showing a completely developed loop of small size.

3—Stereo pair of specimen 1.2 mm. wide showing outpushing of shell on sides of medial depression.

4—Stereo pair of specimen 1.2 mm. wide showing loop formed about a spine by the overlapping of individual spines.

5—Specimen 1.5 mm. wide showing completely developed loop. Note general similarity to Figure *3*, except for loop.

6—Specimen only 1.1 mm. wide with completely developed loop enclosing spine.

7—Brachial view showing incompletely developed loop on pedicle valve of specimen 4.0 mm. wide.

8—Specimen 1.4 mm. wide showing completely developed small loop and other spines on shell.

9—Specimen 1.3 mm. wide with completely developed loop.

10—Specimen 1.1 mm. wide with spine enclosed in loop. Note similarity to Figures *3* and *5*.

11—Specimen 1.0 mm. wide with unusually wide medial depression, and with loop broken off and lying on the shell.

12—Specimen 1.1 mm. wide. This specimen is more quadrate in outline than most of the others.

13—Large specimen, 2.6 mm. wide with loop well preserved near beak, and with several other spine bases.

14—Larger specimen, 3.5 mm. wide with well preserved loop and many spine bases.

15—Three isolated spines with the loop attached. The longest of these is 2.3 mm. long.

tachment may be accomplished by cementation of one valve, by cementation of the pedicle, or by some sort of spine arrangement. Etheridge in 1876 reviewed the opinions of several earlier workers regarding attached forms, and particularly those attached by means of spines. He described several specimens from the Lower Carboniferous of Scotland which were attached to crinoid stems by means of "grasping" or encircling spines, and referred them to the genus *Productus*. Two types of attachment are shown in Etheridge's illustrations. His Figure 11, on Plate 24, shows a specimen attached to a crinoid stem by two encircling spines rising from near the umbonal region of the pedicle valve and individually forming a loop encircling the stem. Most of the other illustrations are of specimens attached by "grasping" spines extending from the margins of the pedicle valve.

Oehlert in 1887 used Etheridge's material as the basis for a new subgenus of *Productus* and called it *Etheridgina*. Hall & Clark (1892) reproduced Etheridge's illustrations and used the same *Etheridgina* but did not mention additional specimens. Thomas (1914) presented an extensive discussion of the spines in the productids.

Greger (1920) illustrated attached specimens from the Louisiana limestone but they were attached by cementation of the pedicle valve, or by spines extending from the margins of the valve. He also used the name *Etheridgina*. In Williams' report (1943) on the Louisiana these same forms were regarded as being conspecific with *Leptalosia scintilla* (Beecher). Neither Greger nor Williams illustrated specimens like those being described here.

In 1928, Muir-Wood made several references to *Etheridgina* and suggested that the spines along the hinge, "were apparently flexible in life, as they are frequently found clasped round slender crinoid stems."

PRESENT MATERIAL

All specimens presently being studied are somewhat like the one illustrated in Etheridge's Figure 11 mentioned above, with encircling spines. None of them has "grasping spines" extending from the edge of the pedicle valve.

Among the many specimens available there are represented many successive stages of growth and development of the shells and of the spines.

The smaller and more immature individuals that range from 0.6 mm. to 1.5 mm. in width are oval to subrectangular in outline. Both valves are present in most specimens. On the pedicle valve a small groove extends anteriorly from near the beak about three-fourths the length of the valve. This groove is more pronounced on some shells than on others. On either side of the groove, near the midlength, a small node is present and appears to be an outpushing of the shell wall. Some specimens have other small nodes and spines elsewhere on the shell, but most of them are smooth.

In slightly larger specimens (1.0 mm. to 2.5 mm.), most of which appear to be more fully developed, the small nodes adjacent to the grooves are higher and curve towards each other forming an arch over the groove. Most of these specimens are somewhat spinose in the marginal region but do not have spines extending from the edges. Many of them are smooth. In a few of these intermediate specimens the spines form a complete loop across the groove and some enclose a spine fragment.

In all larger individuals, up to 7 mm., the loops are completely developed. In some the looping spines seem to abut end-to-end, but in others they overlap. Those which abut meet directly over the middle of the groove, and in some individuals the abutting is accompanied by a localized thickening of the ends of the spines. In most of the overlapping variety the separate spines lie close together and essentially fuse into a loop, but in a few specimens, each separate spine becomes an encircling loop. This is the nature of those illustrated by Etheridge.

In many specimens the loop encircles a fragment of a crinoid or brachiopod spine. However, the majority of specimens in the collection are free and have complete but empty loops. Also abundantly preserved are many isolated spine fragments, each with an encircling loop attached, but from which the rest of the valve has been broken.

The specimens which approximate at least 3 to 5 mm. in width are clearly representatives of the genus *Productella*. This genus is well represented in the Louisiana

limestone. Williams recognized only the species *P. pyxidata* Hall, but commented on the "considerable variation among individuals. . . ." There is considerable variation among the smaller specimens but they are too immature to allow specific differentiation.

Several specimens of approximately 7 mm. width are available. On some of these the loops are present near the beaks and are well preserved; on others they are worn and appear only as low stumps. Yet on still others the beak region is smooth and there is no trace of the spines having been there. Larger specimens of *Productella*, 16 to 20 mm. in width, are abundant in the shaly layers of the Louisiana limestone but they do not bear traces of these attachment spines; they are, however, spinose elsewhere on the shell. It seems then that as the individuals matured they became separated from the original attachment by the breaking or sloughing off of the loop.

The size of the spines and loops can be seen in the illustrations (Pl. 74). They are the same diameter on small and large specimens, and do not seem to enlarge in diameter nor grow in height as the shell grows.

Although some brachiopod spines seem to be developed at the margins of the shell by the edge of the mantle, this does not seem to be true of these loop-forming spines. It also seems very unlikely that they developed in response to any thigmotropic stimulation or that they contained tendons or filaments that could have been used as grasping devices. The manner in which the loops are formed by abutting spines seems to eliminate the possibility of the presence of such structures. Although some loops are present which have developed abnormally they were probably aberrant as the result of some accident or breakage during growth.

In two thin sections prepared the spines are shown to be hollow and to be outpushings of the shell wall. It cannot be clearly determined whether they were open on the distal end. In the more primitive specimens, where they are only low nodes, there is no opening discernible, and on the larger specimens the only spines with open ends are broken and the nature of a complete spine cannot be determined.

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INTRASPECIFIC VARIABILITY IN CONODONTS: *PALMATOLEPIS GLABRA* ULRICH & BASSLER

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ABSTRACT—Three hundred and fifty representatives of *Palmatolepis glabra* Ulrich & Bassler, collected from a single sample of the late Devonian Saverton Shale of Illinois, are used to illustrate intraspecific variability in conodonts. The main types of variation are discussed and the various morphologic features are evaluated for taxonomic use. The study indicates that a conservative philosophy of speciation and careful study of large numbers of individuals must be applied to conodont species if they are to attain widespread use by the general stratigrapher.

INTRODUCTION

IN RECENT years, improvement in the methods of recovery of conodonts from all kinds of sediments has led to a growing resurgence in the use of the fossils for solving stratigraphic problems. The new data accumulated from this renaissance focuses attention on the gross inadequacies of existing conodont classification—classification based in general on narrow concepts of typological species. Although a few specialists recognize the high degree of intraspecific variability exhibited by the microfossils and carefully seek practical species limits, many workers persist in employing a narrow interpretation of the species. As a result, published faunal lists intended as aids for stratigraphic correlations are commonly misleading or even unusable, owing to the large numbers of intrapopulation variants which have been described as distinct taxa. The resultant overwhelming number of species, bewildering to the general stratigrapher, tends to restrict the use of conodonts to relatively few specialists.

Recognizing this problem, Ellison in 1941 clarified the taxonomy of the Pennsylvanian conodonts by placing in synonomy many species based only on minor differences in ornamentation. Such revisions are in order also for conodonts of many other ages. In 1956 Müller outlined and discussed this problem, and in the same year Tatge proved wide limits of variability in a quantitative biometric study of the genus *Gondolella* from the German Triassic, thus strengthening the case for use of broad concepts of species.

The purpose of this paper is to illustrate and discuss the complexities in conodont variability, to evaluate the morphologic features upon which taxonomic differentiation may be based, and to emphasize the need for adoption of a conservative taxonomy based upon consistent similarities in a large number of specimens. To accomplish this we have illustrated the variability shown by 350 individuals of a single species selected from a single sample. Other species have been studied in the same manner with comparable results, so we judge the conclusions drawn from this example to be valid and applicable to many conodont species.

We appreciate the help of Samuel P. Ellison, Jr., A. Bryon Leonard, Carl B. Rexroad, David H. Swann and H. B. Willman. All critically read the manuscript and offered suggestions for its improvement. This study is published with the permission of the Chief, Illinois State Geological Survey.

PROBLEMS OF CONODONT CLASSIFICATION

Although conodonts are enigmatical elements of unknown organisms, for more than a century they have been considered as discrete fossils, and a complete hierarchy of classification with familial, generic, and specific categories based on this concept is well established. Within the past twenty-five years, however, several workers (Schmidt, 1934; Scott, H. W., 1942; Rhodes, 1952, etc.) have reported "assemblages," each of which is interpreted as remains from a single conodont-bearing animal. These so-called "natural assemblages" contain as

many as 10 to 20 specimens representing four or more different types of conodonts that formerly were considered unrelated; for these, formal generic and specific names based on entire "assemblages" have been proposed (Rhodes 1952). The result is two classifications—one based on disjunct parts, but of practical and long-standing value, the other based on essentially complete but rarely preserved entire complements. Recently Moore and Sylvester-Bradley (Moore, 1957, p. 1181–1183) suggested solving this problem by amending the *Regles* of the International Commission on Zoological Nomenclature to allow the use of a classification based on *parataxa*. This would legalize the continued use of separate names for the elements of assemblages.

In the following discussion the terms *genus* and *species*, with few exceptions, are applied to taxa based on discrete conodont elements. Where the terms are applied to natural assemblage taxa or taxa used in the normal zoological sense, such usage is indicated.

KINDS OF CONODONT VARIABILITY

Variability within a natural species represents the total effect of an exceedingly complex interaction of genetic, physiological, and ecological factors. Müller (1956b, p. 1330–1331) has briefly summarized three main kinds of intraspecific variability in conodonts: (1) Variation within a single natural assemblage; (2) ontogenetic transformation; (3) variation within a population (normal intraspecific variability). To these we add: (4) effect of injury and regeneration; and (5) variation produced by genetic trends and natural selection.

In modern invertebrate faunas variability and its causes are not well understood. It therefore will be difficult indeed to learn the details and meaning of variation in conodonts which are not only extinct and of unknown zoological affinity but whose physiological functions have not been ascertained. Despite these handicaps, conodonts lend themselves to studies of variability because: (1) specimens are exceedingly abundant; (2) the stratigraphic occurrence of conodonts in Paleozoic rocks, despite the gaps apparent in the literature, is one of the most nearly complete in the fossil realm; (3) each specimen carries a record of its ontogenetic history; (4) preparation and examination of great numbers of specimens is both easy and rapid; and (5) conodonts are resistent to weathering and to abrasion so that specimens are commonly perfectly preserved and are suitable for detailed study. Nevertheless, variability of conodonts has received scant attention from most authors, and ten to twenty subjective synonyms for a single species are not uncommon.

VARIATION WITHIN NATURAL ASSEMBLAGES

Although natural assemblages are exceedingly rare, the degree of variation found in assemblages referable to the same natural species and in elements from a single assemblage gives us an idea of the kind and amount of variability that should be allowed in species, based upon disjunct elements for which no natural assemblages are known.

In 1952 Rhodes published a study for which he had examined more than 150 natural conodont assemblages of Pennsylvanian age. Since all were referable to only three natural genera and species, he was able to compare significant numbers of specimens belonging to the same natural species and to arrive at the following conclusions:

1. Some assemblages contain components that show a complete gradation from one "form" genus to another.
2. From assemblage to assemblage, platform types are in general more variable than bar and blade types. Especially notable are differences in outline of the plate, thickness of platform relative to height of blade, and ornamentation on the platform. In the same element of several assemblages, platform ornamentation may range from smooth to ridged, and ridges may further vary in direction, length, and relief.
3. Within an assemblage some platform types (polygnathids) vary only in minor details of platform ornamentation.
4. Among bar and blade elements there is notable variation in the flexing of the main bar, the height of the anterior part of the bar, and in the distance between denticles.

Rhodes thus establishes the general range

and magnitude of variability in conodonts and indicates that both may be great.

VARIABILITY RESULTING FROM ONTOGENETIC DEVELOPMENT

Major changes in shape and proportions may occur during the life history of a conodont. Hass (1941), in a study of the microstructure of species belonging to the order Conodontiformes, pointed out that nonfibrous conodonts grow by the successive addition of layers of material on the upper side. The laminated structure is concave downward and is built up about the basal cavity, or point of attachment. Since each layer is irregular in thickness, mature specimens may be morphologically very different from juvenile stages. Earliest stages have only the basic characteristics of the adult, but with each successive growth layer each species follows its own ontogenetic pattern. In simple cones growth takes place about a single axis. In platform types growth centers about several axes.

Despite the major changes in morphology possible during ontogenetic development, generic and specific identification of juvenile individuals can generally be solved if given serious attention. As has been demonstrated by Hass (1941), thin sections reveal the ontogenetic growth pattern contained within each specimen and can serve to relate immature and mature forms. In actual practice, juveniles and adults of conservative species in a population sample can be readily related if sufficiently large numbers (generally more than 25) are studied. Although immature forms generally do not receive the attention justified by their abundance and are commonly misidentified even as to genus, many species have been based on descriptions of immature forms.

Müller points out that, if ontogeny is known, diagnostic features which persist from early growth through all stages of development may be selected as characteristics for new species. All too often, species are based on morphologic features found only in mature or even gerontic specimens. The probability that such features are of significant taxonomic value is low, and the potential stratigraphic usefulness of the species is correspondingly reduced. Text-figure 2 demonstrates that well defined species, although closely related, can be differentiated in nearly every stage of growth.

Furthermore, the study of ontogeny aids in clarifying phylogenetic relationships, as, for example, those of *Palmatolepis glabra* with *P. tenuipunctata* and *P. perlobata*. The latter evolved from the former, and "*glabra* stages" can be found among juvenile forms of its representatives.

MORPHOLOGIC VARIABILITY DUE TO REPAIR OF INJURIES OR SUPPRESSION OF CERTAIN FEATURES

Aberrant specimens resulting from injuries during the lifetime of the conodont-bearing organism are sufficiently common to be considered in the identification and delimitation of taxonomic categories. Numerous abnormal individuals have been recognized and illustrated (Hass, 1941, pl. 13, figs. 4,5,7 and pl. 14, fig. 1; Müller, 1956b, pl. 145, figs. 6–11; Rexroad, 1957, pl. 1, fig. 3). By the detailed examination of thin sections, Hass (1941) has conclusively demonstrated that these abnormalities are the result of repair or regeneration after injuries. If adequate material is studied, most aberrant specimens are identifiable as such. Occasionally slight injuries or mildly suppressed features may not be recognized, and morphologic variability resulting from them may be attributed to other causes. Generally speaking, however, aberrant specimens become troublesome only through lack of adequate information. Invalid species may result from the erection of new species based upon a single, apparently distinctive specimen, which in fact is only a freakish representative of a previously named species, but the difficulty can be greatly reduced if new taxonomic categories are proposed only after study of groups of specimens, rather than single individuals.

The specimens illustrated on Pl. 75, figure 11, and on Pl. 76, figures 15,16,18–20 are aberrant specimens of *P. glabra*, all collected from the same sample. In addition to these the sample contained appreciable numbers of abnormal representatives of many other species. The specimens figured illustrate the most common types of abnormalities. Specimens illustrated in Pl. 1, figure 11, and Pl. 76,

figure 15, have a noticeable offset in the anterior carina, apparently due to the repair of an injury. This type of abnormality is common in bladelike genera. Outline of the inner rim of the specimen figured on Pl. 76, figure 16, is irregular due to a temporary local retardation of growth. That growth layers are deposited over the injured portion is evidence that breakage was prior to the death of the conodont-bearing animal.

A specimen figured by Müller (1956b) similar to the unusual individual figured on Pl. 76, figure 19, is attributed to a injury during early growth. We have observed other specimens which have been deformed in other ways, for example, by neoplastic deposition of secondary material during a late development stage. One such specimen of *P. glabra* has a lobelike projection on the inner rim which alters the outline of the plate to one quite similar to that of *P. tenuipunctata*.

The denticulated secondary carina developed near the parapet of the specimen on Pl. 76, figure 18 may be due to an injury. The specimen is characteristic of *P. glabra* in all other aspects. Some workers would consider the occurrence of such a secondary carina as sufficient evidence for the establishment of a separate species. However, it is not at all uncommon to find specimens with additional keels, carinae, or lateral limbs, that might be confused even as to correct generic reference.

The posterior end of the specimen on Pl. 76, figure 20, apparently was broken at an early growth stage. When the injured portion was regenerated, two carinae rather than one developed posterior to the central node. Also this end of the plate, due to retardation of growth, did not attain the size of the anterior end. The extreme posterior tip of the plate may have been broken subsequent to the death of the animal.

NORMAL INTRASPECIFIC VARIABILITY

The natural population of any given species will always show some degree of variability even though the extent may differ greatly in separate populations. In its entirety, a species population forms a number of unbroken series of individual variations that are morphologically similar. When the variations in a large sample are studied, each can be seen to be intergradational and inconspicuous, although some occur with greater frequency than others. When only a small sample is examined, the range of variation is incomplete and some variants assume an apparent distinctiveness which may lead the investigator, ill-advisedly, to base new species on them.

In order to understand the full stratigraphic significance of any given conodont specimen, its relationship to the entire species population belonging to a given time plane must be known as well as the specimen's relationship to the evolutional history of the species. In the latter case it is commonly necessary to know the nature of variations within the entire population in order to distinguish trends which may be phylogenetically significant (see discussion of *Palmatolepis glabra* ζ morphotype). Such studies of successively younger or older populations delineate in detail phylogenetic lineages and indicate precisely the earliest occurrences of new species.

One of the main advantages to the conodont specialist is the general availability of quantities of material that can be used to assess the true practical limits of species. This opens the way for biometric analyses, although the great diversity and independence of conodont variables reduce somewhat the practicality of such treatment. Visual comparisons of adequate samples, such as utilized in the following case study of *Palmatolepis glabra*, will in most cases enable paleontologists to define in detail the limits and kinds of variability within a species population. In some cases the comparisons may be aided by construction of a diagram such as Text-figure 3.

VARIATION RESULTING FROM EVOLUTIONAL PROCESSES

Unlike the neontologist whose populations are restricted essentially to one time plane, the paleontologist must incorporate a third dimension in his concept of a species. Even though a species can be shown to be an objective entity, isolated from other species at a given time, in its entirety it is part of a continuously evolved lineage. It must therefore be defined by more or less arbitrary boundaries in time.

In erecting species which can be identified consistently through a stratigraphic interval and are therefore useful as indices, the investigator must base his species on characters that have phylogenetic significance. To do this a succession of populations must be examined and their variations analyzed. When the modes of variation have been determined, the evolutional drift or persistence of characters can be established.

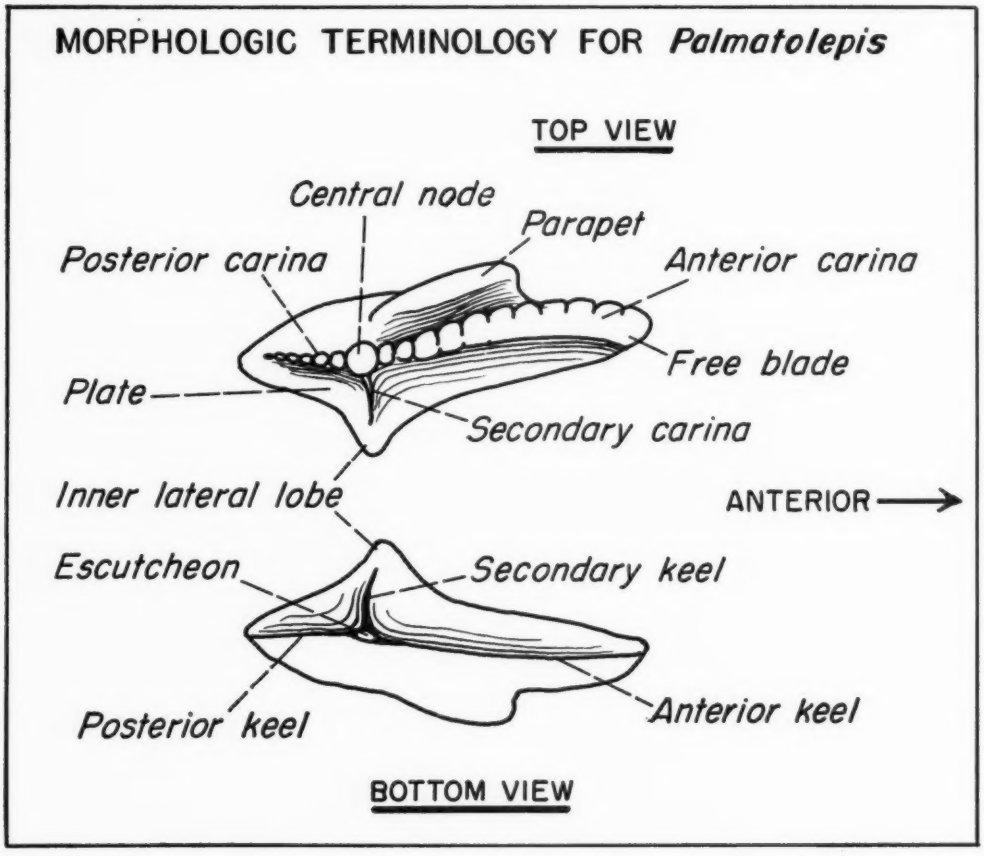
Whereas uninterrupted stratigraphic occurrences are rare in most fossil phyla, the ubiquitous stratigraphic occurrence of conodonts in the Paleozoic offers an unusual opportunity for investigators to work out detailed phylogenies of stratigraphically useful lineages.

INTRASPECIFIC VARIATION IN *PALMATOLEPIS GLABRA* ULRICH & BASSLER

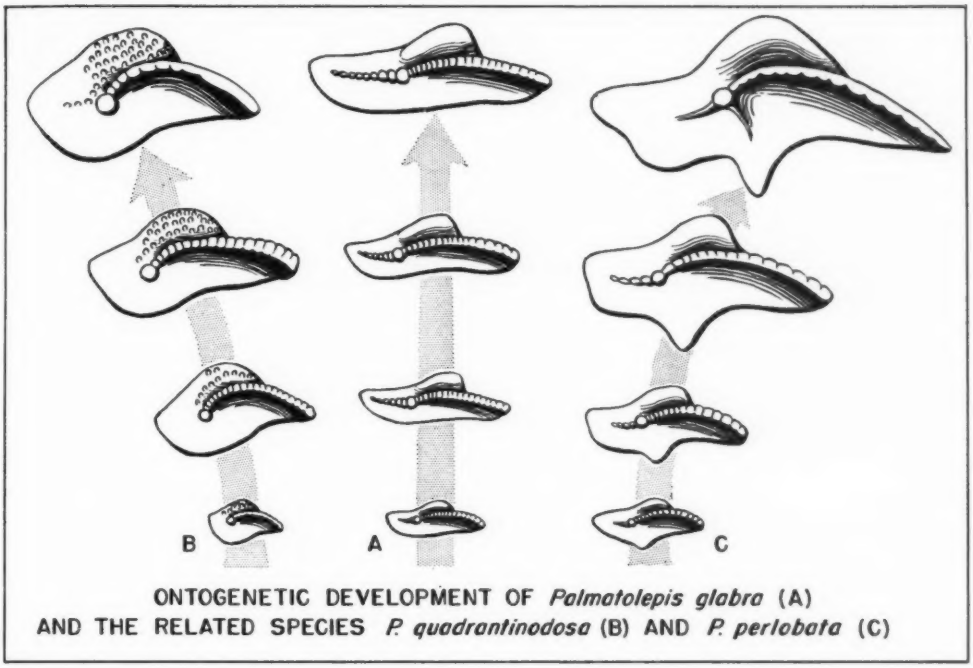
Species variability in conodonts can best be illustrated by a specific example. For this purpose we have chosen the Devonian species *Palmatolepis glabra* Ulrich & Bassler. It is remarkably suited to this study for a number of reasons:

(1) The taxonomy has been clarified recently in an excellent comprehensive study by Müller (1956a). Müller's synonomy of *P. glabra* is complete (1956a, p. 25) and is not repeated here.

(2) The stratigraphic occurrence of *P. glabra*, both in Europe and North



TEXT-FIG. 1—*Palmatolepis* sp., diagram illustrating terminology used in the description of platform type conodonts.



ONTOGENETIC DEVELOPMENT OF *Palmatolepis glabra* (A) AND THE RELATED SPECIES *P. quadrantinodosa* (B) AND *P. perlobata* (C)

TEXT-FIG. 2

America, is well known. It is one of the common Devonian platform conodonts.

(3) *P. glabra* is a relatively simple form and, although often cited in the literature is not generally confused with other species.

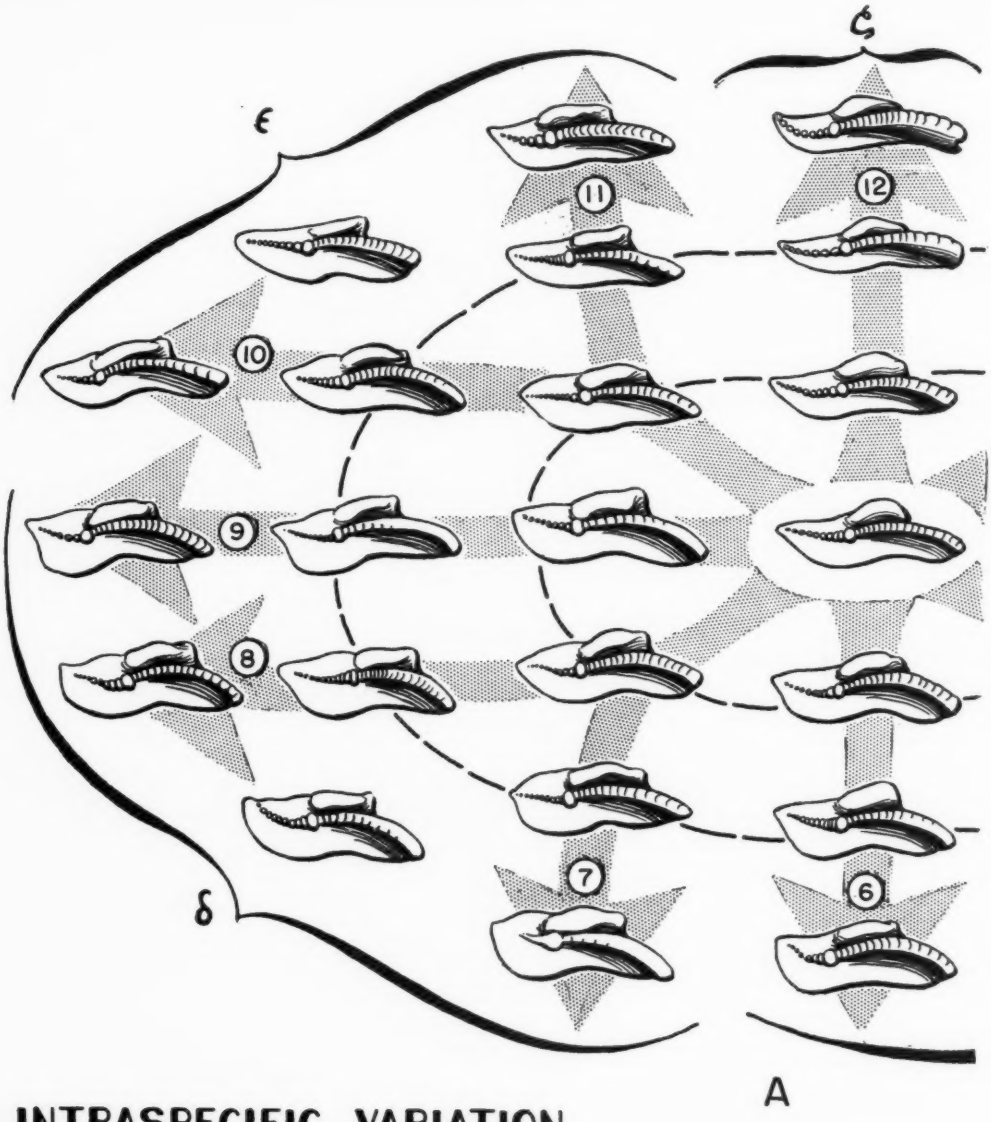
(4) The phylogenetic history of palmatolepids is fairly well known (Müller 1956a, p. 34–36) and several important species apparently evolved from *P. glabra* during late Devonian time.

This study is based on a single sample from the Saverton Shale (Upper Devonian) 18 to 19½ feet below the base of the Glen Park Formation. The locality is in the bluffs of Mississippi River one and a half miles south of the village of Atlas, Pike County, Illinois, near the Illinois Highway 96 (center SE¼ sec. 25, T. 6 S., R. 5 W.). More than 100 kilograms of material, yielding thousands of unbroken conodonts, have been processed from this zone. The sample represents essentially one contemporaneous population. There is no sign of mechanical sorting and almost every species present is represented by a complete series of growth stages.

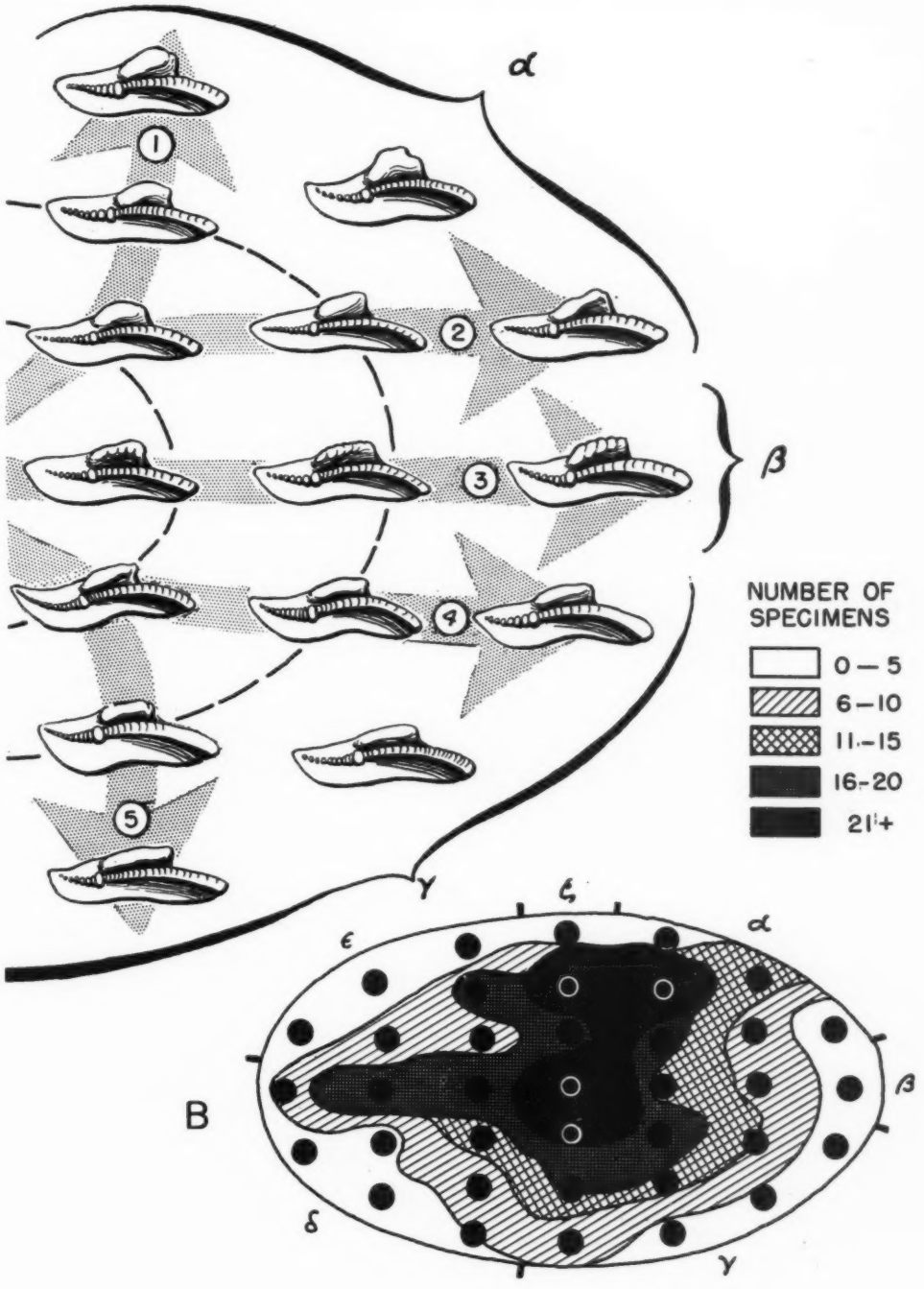
Palmatolepis glabra is abundant in the collection, as are the palmatolepid species *P. regularis*, *P. quadrantinodosa*, *P. perlobata*, and *P. subperlobata*. Examination of hundreds of adult specimens showed these latter species to be completely distinct from *P. glabra* even though all have immature stages that are similar. Abundant immature specimens belong to *P. glabra* were studied from the same collection but for the purpose of illustrating normal intraspecific variability, only the first 350 mature specimens were picked to represent the species population. These specimens are shown in Text-figure 3. Ontogenetic stages are represented separately in Text-figure 2.

CONSTRUCTION AND INTERPRETATION OF TEXT-FIGURE 3

The large number of variables and the low correlation between them makes simple univariate or even bivariate analysis of conodont morphology impractical. Such complex relationship can be expressed by using multivariate analysis, of course, but



TEXT-FIG. *3*—Diagrams illustrating intraspecific variation in 350 representatives of *Palmatolepis glabra* Ulrich & Bassler. 3A, principal variants selected from a single sample of Saverton Shale from western Illinois. Related variants are grouped into morphotypes designated by Greek letters. The central figure represents the norm. Dotted rings indicate the degree of divergence from this form. The arrows, numbered for reference, delineate trends of variation within the morphotypes. 3B, diagram showing the frequency distribution of the principle variants. Dots and circles represent the positions of the 37 variants illustrated in 3A. The remaining specimens were plotted according to degree of resemblance to one or more of the illustrated forms. The density pattern was then determined by interpolation.


α
β
γ
1
2
3
4
5
NUMBER OF SPECIMENS
0 — 5
6 — 10
11 — 15
16-20
21+
B
ξ
α
β
γ
δ
ε

the method involves many laborious measurements and computations. Because of these difficulties, we devised a technique by which we illustrated the principal morphologic variants (Text-fig. 3A) and then recorded the frequency distribution of these variants on a graph (Text-fig. 3B). The diagrams then give an orderly picture of the species limits as well as the relative significance of several trends of variation. As here presented, the method is relatively unrefined; however, our purpose is not to propose a method of variation analysis, but to illustrate and discuss a reasonable basis for conodont speciation.

One procedure has been devised by Trueman and his colleagues to characterize populations of British nonmarine clams (Imbrie, 1957). In their method each population is first examined for variants. A diagram is then made by arranging illustrations of the variants in a subjective pattern that represents the morphologic trends shown by the population. A distribution diagram is then constructed, using a reference framework based on the diagrammatic arrangement of the population variants, and the remaining members of the population are marked on the diagram according to their resemblance to the illustrated variants. The relative strength of the various morphologic trends is graphically shown by the density of the marks on the distribution diagram. Type specimens are then chosen for each of the more abundant variants as well as the less common but more divergent variants, and all are considered species.

Our procedure in studying conodont populations is similar in many respects to that described above but it has one major difference. Rather than interpreting intrapopulation variants as separate species, we have used the term *morphotype*, as applied by Sylvester-Bradley (1958), for major groups of variants. The morphotypes are distinguished by Greek letters. If future studies of *P. glabra* populations indicate that any of the morphotypes described in this paper are sufficiently distinct from other palmatolepids, they may be given formal names and considered species. Until that time, we are not burdened with a list of arbitrarily defined species which are gradational and may be without stratigraphic value.

The details of construction of Text-figure 3 are relatively simple. To eliminate bias in the selection of representative specimens, the first 350 unbroken mature individuals encountered were used in the construction of Text-figures 3A and 3B. These specimens were then photographed to facilitate their comparison. The variants were sorted into morphotype groups on the basis of similarity of characters. For example, specimens with nodose parapets were grouped together in the β morphotype; specimens with narrow plates and reduced parapets were considered as belonging to the ζ morphotype. In this manner the population was divided into six morphotype groups. The division is somewhat arbitrary and other workers might recognize fewer or more groups. It is doubtful, however, that such differences would significantly affect the conclusions drawn herein.

One specimen, representing the most common form present in the population studied, was placed in the center of the diagram. Unfortunately the original description and illustrations of *P. glabra* by Ulrich & Bassler (1926) are not sufficiently detailed for us to consider this specimen identical in form with the holotype.

Thirty-six additional specimens illustrating the limits of variability of the various morphotypes were arranged in three concentric rings around the central or "normal" specimen. These rings—inner, intermediate and peripheral—correspond to the degree of divergence of the specimens from the "normal" form. Several morphologic trends were evident in the morphotypes of this population. These trends are delineated by arrows in Text-figure 3A. Each trend is composed of a series of specimens which illustrate a gradual and progressive divergence of one or more characters from that of the "normal" form. As an example, Trend 9 represents the development of a blunt subquadrate posterior tip of the plate.

Text-figure 3B graphically illustrates the relative significance of the morphotypes and their variation trends. The diagram was constructed by plotting 350 points, one for each specimen in the sample population, on a grid based on Text-figure 3A. The position of each point was determined by the resemblance of individuals to one or more of the figured variants. The density of the points

was then contoured, forming an accurate representation of the frequency of occurrence of the individual variants.

DESCRIPTION OF MORPHOTYPES OF *PALMATOLEPIS GLABRA*

The following descriptions are based solely upon the 350 individuals of the population studied. Six morphotypes are discussed, although this number is arbitrary because each group is transitional with other morphotypes. Theoretically the number of intra-population variants is infinite. It seems practical to describe only the six most important.

Morphotype α.—The morphotype α group is characterized by a simple lobate parapet, which increases in height gradually toward the outer edge of the specimen. The trough is broad and shallow, unlike those of the other morphotypes. Posteriorly, the plate tapers to a rounded tip. The inner edge of the specimen may be slightly sigmoidal or nearly straight. The α morphotype is quite common in the study population with 78 of 350 specimens assigned to this category.

The most common variation tendency (Trend 1) is toward the development of an increasingly prominent crescent-shaped parapet. The inner edge of the plate varies from slightly sigmoidal to nearly straight or even slightly convex in some specimens. Specimens characteristic of this trend are shown in figures 2–5 on Plate 75. Figures 2–4 on Plate 75 illustrate the ontogenetic development of the α morphotype. The similarity in outline of the various stages is notable.

A few individuals (Trend 2) developed straight rather than crescentic parapets, which are set at an acute angle to the anterior carina. This parapet forms a subtriangular outer lateral lobe with a posterior ridge and an anterior trough. Plate 75, figure 1, illustrates this characteristic.

Most representatives of the α morphotype have a narrow plate, with a length to width ratio of about 4:1. A few specimens (for example, Pl. 75, fig. 5) have wider plates (length to width 3:1). *Palmatolepis tenuipunctata* may have evolved from *P. glabra* α by such widening of the plate and subsequent development of an inner lateral lobe.

Morphotype β.—Specimens of *Palmatolepis glabra* possessing a nodose parapet are assigned to the β morphotype. Müller (1956a) considered this character a function of ontogenetic stage because he found nodes on the parapet of many mature and gerontic individuals of *P. glabra* from Europe. In the population examined for the present study several very immature specimens (Pl. 75, figs. 7, 8) also exhibit nodose parapets so it seems likely that the ontogenetic stage of development is not the sole controlling factor.

Forty-two of the 350 specimens possess nodes on the parapet but no other morphologic character remains constant within the β group. Furthermore, β forms are referable to every other morphotype, with the single exception of the ζ morphotype. The β morphotype must therefore be considered a completely arbitrary grouping which includes unrelated forms having only one character, the nodose parapet, in common.

The β morphotype serves as an excellent example of the need for careful evaluation of morphologic characteristics used to delimit taxonomic units. The mere presence of an apparently distinct character, such as a nodose parapet, should not be considered sufficient evidence for the erection of a separate taxonomic unit. It is true that the nature of the parapet is extremely important in the delineation of some palmatolepids (*P. quadrantinodosa*) but other morphologic features, such as the outline of the plate, must also be used to define such species. In the case of the β morphotype, there is no supporting evidence for proposing a separate species even though an appreciable number of specimens possessing a nodose parapet have been observed.

Morphotype γ.—Representatives of γ morphotype in general have long narrow sigmoidal plates with gradually tapered posterior ends.

Three distinct morphologic trends have been recognized within this group. Trend 4 illustrates a tendency for the development of a narrow, highly sigmoidal plate with a long, tapered posterior end. Another morphological development, Trend 5, is in the progressive decrease in the relative length of the plate posterior to the central node and increase in the length of the parapet. The outlines of the extreme example in this trend are similar to *P. distorta* Branson & Mehl. The third and most common trend in this morphotype, Trend 6, is for the de-

velopment of a shorter, more blunt posterior end, with an increase in the curvature of the carina. The specimen on Plate 76, figure 12, has an exceptional outward curvature of the posterior carina. Members of this trend show a complete gradation with representatives of the δ morphotype, which is characterized by a blunt posterior end.

The γ form is the most frequently occurring morphologic variant represented in the sample population, with 89 of the 350 specimens. Density in the inner ring in Text-figure 3A indicates that the majority of specimens do not differ greatly from the "normal" specimen. It is not possible to recognize the three morphologic trends in most specimens referred to this inner level. The trends can be differentiated only in specimens referable to the intermediate and peripheral rings.

Morphotype δ.—A relatively short, wide platform with a prominent broad, blunt posterior end is characteristic of the δ morphotype. In general this form also has a relatively thick plate, a heavy ridgelike parapet, and an anterior carina more curved than in the other morphotypes in this population.

The least constant character of this morphotype is the shape of the posterior end. Three broad trends based on differences in its configuration may be recognized: (1) Trend 7—the posterior end of the plate is broad and attenuate and much wider than the anterior part. This feature is well illustrated on Plate 76, figure 9. (2) Trend 9—the posterior end is terminated by a blunt, nearly quadrate tip. The trend is well defined and is the most common variation in this group. On the density diagram (text-figure 3B), this trend is represented by a prominent horizontal linear projection. The majority of specimens referable to δ are similar to Plate 75, figure 21. (3) Trend 8—the specimen illustrated on Plate 75, figure 20, exhibits an especially well-developed quadrate tip with a notch in the outer rim. The notch is considered diagnostic of Trend 8. Since this trend is of little importance numerically it may be merely a minor variation of Trend 9.

Eighty-seven specimens are referable to the δ morphotype, so it has only slightly fewer representatives than the γ morphotype. Additional study may attach considerable evolutionary significance to the δ morphotype. Several species of *Palmatolepis* (for example, *P. inflexa*, *P. quadrantinodosa*, and *P. minuta*) have short, blunt plates similar to *P. glabra* δ. Such species may be closely related to this form and, if so, study of older populations of *P. glabra* should establish the relationship.

Morphotype ε.—Morphotype ε is characterized by a highly sigmoidal plate and subrounded posterior end. The anterior portion of the carina is highly curved, but posterior to the central node it is generally straight.

The angle between carina and parapet and the relative length of the parapet are quite variable within this group. Of two morphological trends recognizable, Trend 10 is the most common and well defined. It is characterized by a sigmoidal plate and a long curved parapet which is parallel to the carina. The specimen on Plate 76, figure 13, is an excellent example, similar in many respects to *Palmatolepis distorta* Branson & Mehl although the cross sections of the plates of the two forms are quite different. The platform of *P. distorta* is much thicker and more highly convex than that of *P. glabra*, which is thinner and nearly flat.

Trend 11 is based on a series of specimens with straight, elongate parapets set at an angle to the anterior carina. The outline of the plate is only slightly sigmoidal and the inner rim of some specimens is nearly straight. The specimen shown on Plate 76, figure 10, is representative of the trend. It is similar to the δ morphotype on Plate 2, figure 5. An individual intermediate between trends 10 and 11 is shown on Pl. 76 figure 14.

As shown by the frequency diagram (Text-fig. 3B), ε is not a common form. Only 32 of the 350 specimens are assigned to it. Rather broad limits have been allowed in defining this form and some unrelated specimens may have been included in the group. If a larger sample from the population were to be studied, subdivision might be practical.

Morphotype ζ.—An extremely narrow, long sigmoidal plate with sharply tapered posterior and anterior ends represents the ζ morphotype. The parapet is greatly reduced or entirely absent in some specimens. The

plate is likewise reduced in width, and a short free blade may be developed at the anterior end (Pl. 75, figs. 16 and 17).

In lateral view the posterior tip of the plate is arched more sharply upward, the carina is higher, the termini of the denticles more distinct and needlelike than those of other morphotypes.

The frequency of occurrence, as shown in Text-figure 3B, strongly suggests that this form may represent a distinct subspecies of *Palmatolepis glabra*. The possibility is further supported by the characteristic immature specimens of this form illustrated on Pl. 75, figures 11–13 and 16. Specimens falling on the inner ring of the variation diagram (Text-fig. 3A) are completely gradational with other morphotypes, especially the α form. We therefore have not proposed a separate taxonomic category for the ζ form at this time. Only 38 representatives of the 350 specimens studied were assigned to this morphotype. The study of additional material, particularly from younger populations, may make such a distinction practical. It is probable that *Palmatolepis gonioclymeniae* Müller, a common species in the youngest Devonian beds, was evolved from *P. glabra* ζ.

EVALUATION OF MORPHOLOGICAL CHARACTERS

VARIATION IN OUTLINE OF PLATE

Examination of Text-figures 3A and 3B leads to the conclusion that gross outline of the plate is a valuable taxonomic characacteristic, whereas details of the plate are not. In our study, the two main variations in gross plate outline are represented by morphotypes δ and ζ, and the frequency diagram (Text-fig. 3A) shows them to be numerically significant. The latter variant, morphotype ζ, is based on relatively broad, short platforms and may be the root that gave rise to such species as *Palmatolepis crepida*, *P. minuta*, *P. quadrantinodosa*, and *P. rhomboidea* (Text-fig. 4). Morphotype ζ, as shown in Text-figure 3A, shows a decrease in plate width and reduction in the size of the parapet. According to Text-figure 3B, ζ is the most important variant in the *P. glabra* population and it seems likely that through time it continues to diverge from the *P. glabra* norm until it is recognized as *P. gonioclymeniae* in the upper part of the *Oxyclymenia* Zone. The relationship is further indicated by the possession of a short free blade in some representatives of both species.

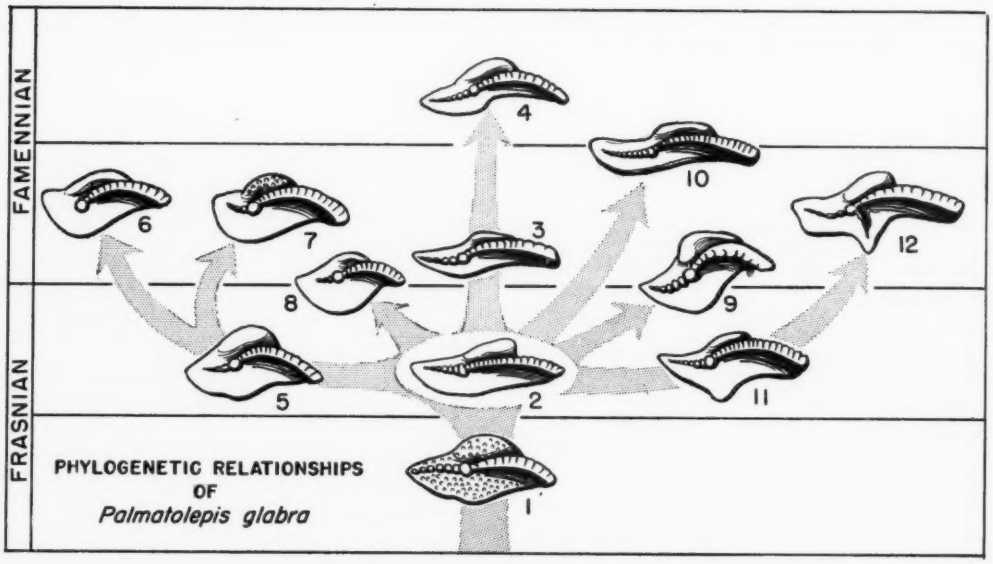
The tendency to develop a lateral lobe on the plate, such as gave rise to *P. tenuipunctata* and *P. perlobata* (Text-fig. 4), has not been observed in our representatives of *P. glabra*, even though Müller considers it to be one of the most successful evolutionary tendencies in the genus. The tendency is seen in several other species of *Palmatolepis* in our sample, however.

Other plate details as notches in the outer rim (Pl. 76, fig. 7), subrounded posterior ends, and minor plate lobes, although of very distinctive appearance, are unreliable and of little taxonomic importance.

DENTICULATION AND CURVATURE OF THE CARINA

The number of denticles on the carina and the extent of their fusion is commonly made a basis for species differentiation. The present study shows both features to be a function of maturity—the number of denticles and their degree of fusion increases with growth of the individual. Fusion carried to the extent that the individual denticles are obscured is a sign of full maturity, although all mature specimens do not necessarily exhibit fused denticles. Denticulation therefore must be given very low priority among the characteristics to be utilized for taxonomic differentiation. Our conclusions suggest that there is probably a need for revision of many species of such genera as *Bryantodus*, *Ozarkodina* and *Spathognathodus*, which are based mainly on the nature of denticulation.

Curvature of the carina has been shown to be an important taxonomic feature among palmatolepids (Müller 1956a), and our study verifies the conclusion. Specimens assigned to morphotype δ (Text-figs. 3A, 3B) show a direct association between increased curvature of the carina and broadening of the plate. The combination of the two in Trend 9 of Text-figure 3A probably produced short, blunt species such as *P. crepida* and *P. rhomboidea* of younger strata.



TEXT-FIG. 4—Diagram showing the morphologic development of *Palmatolepis* Ulrich & Bassler in the Upper Devonian (modified from Müller, 1956a). Species are identified as: (1) *Palmatolepis linguiformis* Müller; (2) *P. glabra* Ulrich & Bassler; (3) *P. glabra* ζ morphotype; (4) *P. gonioclymeniae* Müller; (5) *P. crepida* Sannemann; (6) *P. inflexa* Müller; (7) *P. quadrantinodosa* Branson & Mehl; (8) *P. rhomboidea* Sannemann; (9) *P. regularis* Cooper; (10) *P. distorta* Branson & Mehl; (11) *P. tenuipunctata* Sannemann; (12) *P. perlobata* Ulrich & Bassler.

EXPLANATION OF PLATE 75

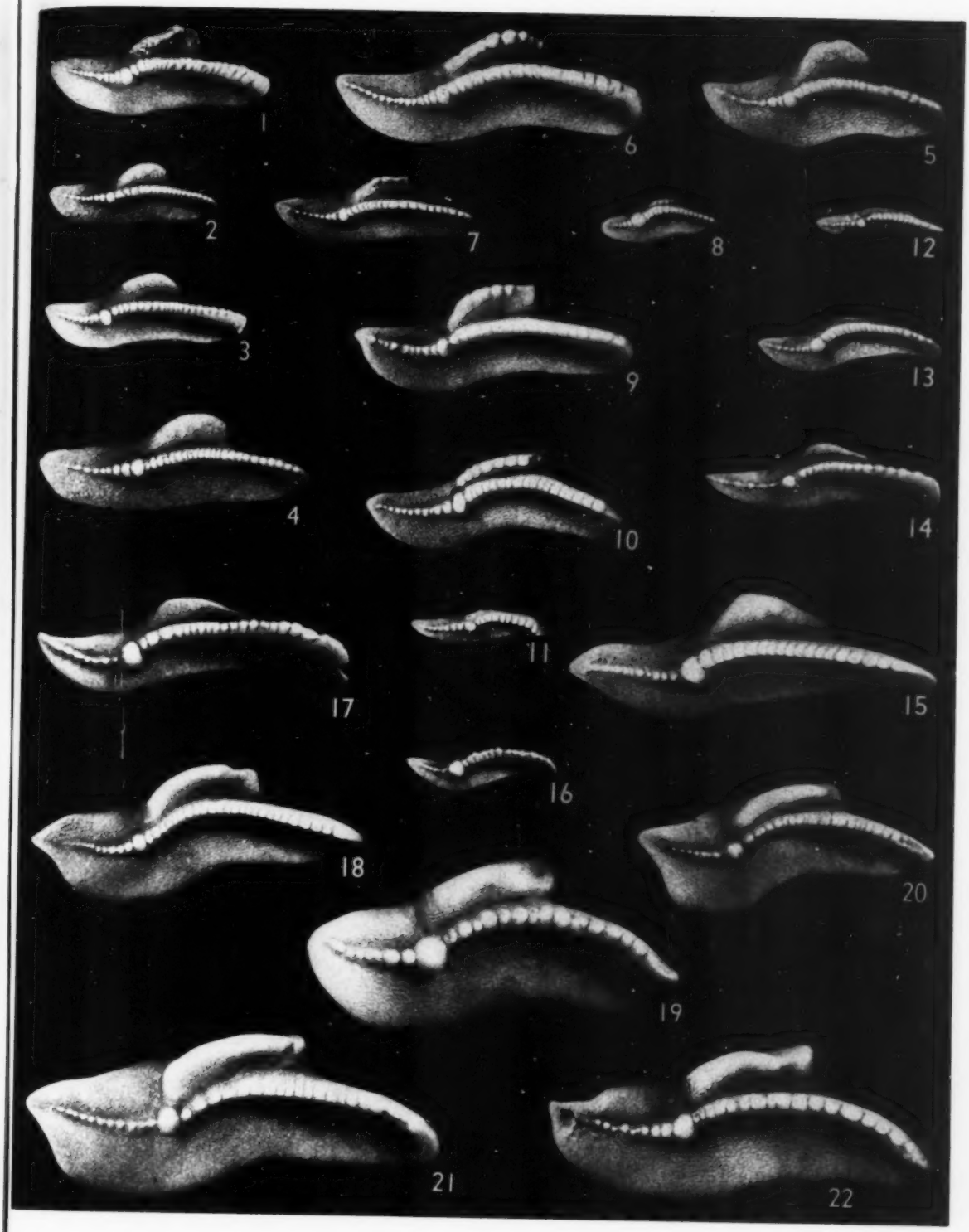
All figures ×45. Figures *1–3,12–14,17* and *19* are dextral specimens and have been reversed. All specimens came from the same sample of the Saverton Shale of western Illinois.

FIGS. *1–5—Palmatolepis glabra* α morphotype. *1*, specimen showing widely flared triangular parapet; *2–4*, three specimens illustrating ontogenetic development of the α morphotype; *5*, specimen with exceptionally broad plate.

6–10—P. glabra β morphotype. *6,9,10*, mature individuals showing variety of parapet shapes; *7,8*, immature specimens with nodose parapets.

11–17—P. glabra ζ morphotype. *11*, immature individual with abnormal anterior blade; *12–15*, series of specimens illustrating ontogenetic development of the ζ morphotype; *16*, immature specimens with short free blade at anterior; *17*, mature specimen with free blade.

18–22—P. glabra δ morphotype. Five specimens illustrating variation in the blunt posterior end characteristic of this morphotype.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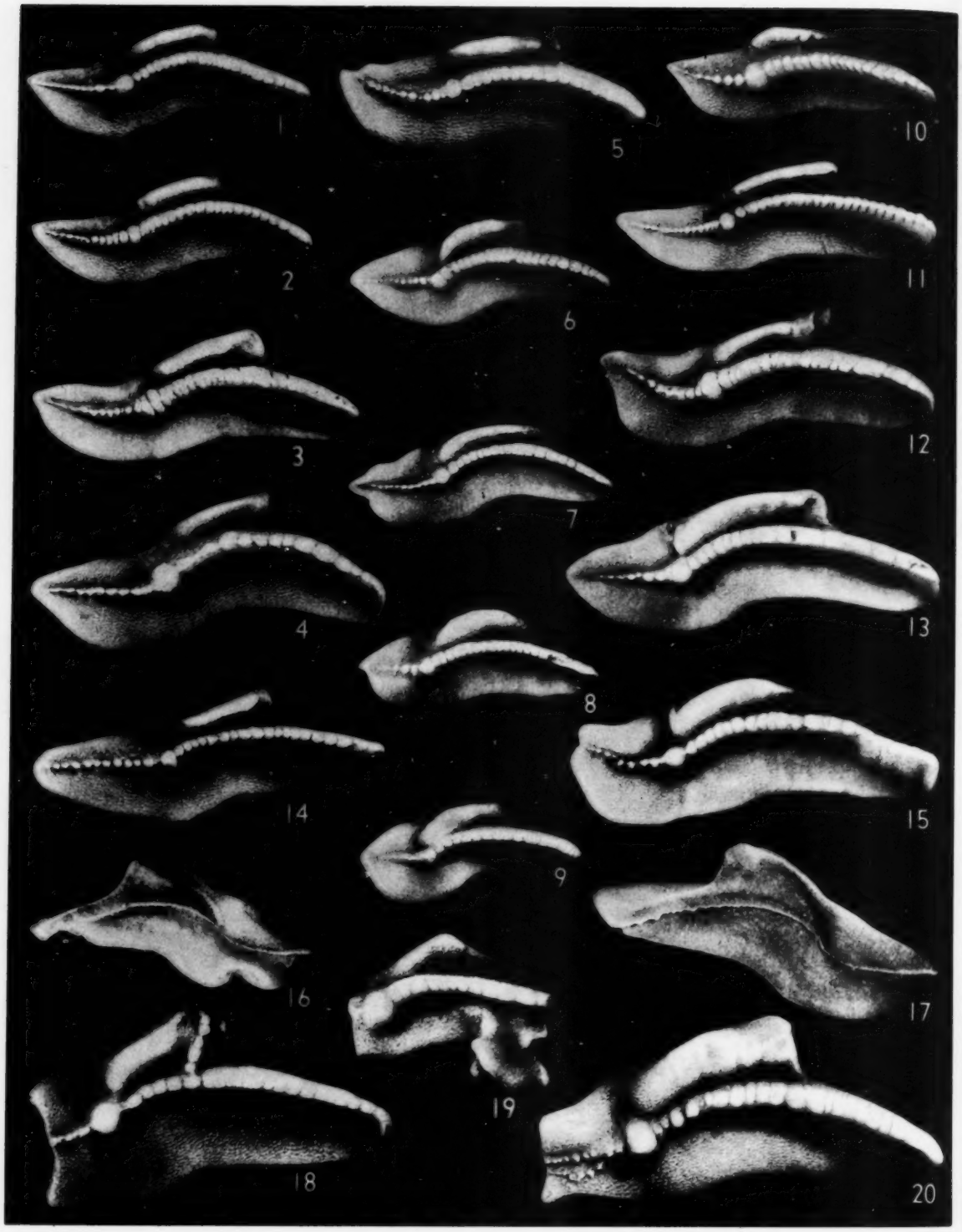
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SHAPE AND ORNAMENTATION OF PARAPET

Palmatolepis glabra characteristically has a simple ridgelike parapet developed near the outer rim of the plate, and the configuration of such a parapet is commonly used to delineate palmatolepid species. Nevertheless, the variants illustrated in Text-figure 3A show considerable variety of shape and ornamentation of the parapet even within a single morphotype. For example: the curvature ranges from straight to crescentiform; orientation may be from closely parallel to the carina or at a considerable angle to it; outline may range from rectangular to wedge-shape; ornamentation can be smooth, slightly irregular, or strongly nodose; and the prominence of the parapet ranges from very strong in the δ form to markedly reduced in the ζ form. Of the above characters only one, prominence of the parapet, seems to have taxonomic value. In morphotype ζ (Text-figs. 3A, 3B), reduction in prominence is closely related to reduction in width of the plate and is part of a trend from which the species *P. gonioclymeniae* was derived.

Müller (1956a) indicates that another modification of the parapet is important in the *Palmatolepis linguiformis, P. glabra, P. distorta* phylogenetic series which evolved through a gradual lengthening of both plate and parapet. A similar development can be seen in some specimens in Trend 5 (Text-fig. 3A) of the γ morphotype in our population, but its significance is not clear.

ORNAMENTATION OF THE PLATE

Palmatolepis glabra, like most species of the genus, has a plate ornamented by fine sinuous ridges that range in prominence from obscure to distinct. Our studies show no correlation of plate ornamentation with other features, and we believe it to be of little taxonomic value. Since *P. glabra* lacks the heavy nodes and ridges characteristic of some other platform species, we have studied plate ornamentation in such genera as *Ancyrognathus, Polylophodonta* and *Polygnathus*. Our conclusion is that species based on minor differences in plate ornamentation are in general invalid. Gross features of relief and pattern are exceedingly useful in many species but must be used as diagnostic characteristics only after careful investigation of large numbers of specimens.

OTHER CHARACTERS

General characters such as the tapered

EXPLANATION OF PLATE 76

All figures ×45. Figures, *1,3,5,9,11,14,16,17*, and *20* are dextral specimens and have been reversed. All specimens came from the same sample of the Saverton Shale of western Illinois.

FIGS. *1–4,11–12—Palmatolepis glabra* γ morphotype. *1*, specimen possessing irregular inner rim; *2–4*, mature specimens showing variation in the central node; *11*, specimen illustrating the "norm" for shape of plate and parapet; *12*, specimen with sharply deflected posterior end.

5–7,9—P. glabra δ morphotype. *5*, illustrates variant in which sides of the plate are nearly parallel; *6*, the most commonly occurring variant; *7*, specimen with irregular posterior end and an unusually long parapet; *9*, specimen with broad spade-shaped posterior end.

10,13,14—P. glabra ϵ morphotype. *10*, extreme variant with nearly straight and subparallel lateral rims; *13*, specimen with elongate parapet and sigmoidal plate similar to *P. distorta* Branson & Mehl; *14*, specimen intermediate between extreme variants of trends 10 and 11 of Text-fig. 3A.

15,16,18–20—P. glabra. Abnormal individuals resulting from imperfect repair of injuries; *15*, specimen with a lateral offset at the anterior end of the carina; *16*, illustration of temporary retardation of growth in local areas of the inner rim (compare with normal specimen in fig. *17*); *18*, specimen with abnormal secondary carina developed in place of anterior end of parapet; *19*, illustration of "tumorlike" growth on inner rim—probably due to injury to the secretory tissue; *20*, specimen showing result of imperfect regeneration of posterior end. An additional secondary carina was developed to strengthen the plate.

17—P. glabra δ morphotype. Ventral view of uninjured specimen illustrated for comparison with fig. *16*.

plate, prominence of the central node, and the deflection of the posterior end of the carina are relatively constant features and are shared with many species. Such features are considered to be of generic and familial rank.

CONCLUSIONS AND SUGGESTIONS

The *Palmatolepis glabra* case study illustrates the extremely high degree of intrapopulation variability possible within a conodont. This study also emphasizes the necessity of large collections of specimens. If only a few individuals were examined, most workers would consider extreme variants (e.g., peripheral specimens in Text-fig. 3A) sufficiently different from the "normal form" of *P. glabra* to justify their considerations as separate species. The study of adequate material conclusively demonstrates the complete intergradation of these forms.

Conodonts are easily obtained from almost all types of sediments and there is rarely reason for publication of studies based upon insufficient material. Unfortunately, many published faunal descriptions are based on little material. As a result the literature contains large numbers of fatuous species based upon intrapopulation variants. Faunal lists from essentially equivalent stratigraphic units commonly bear little resemblance to one another, owing to narrow concepts of typological species.

Extensive taxonomic revisions are in order for conodonts of all ages. Several basic principles, illustrated in the *P. glabra* case study, must be recognized in such a revision and allowed for in future taxonomic studies. These principles are not necessarily new. Many workers have recognized and made proper allowance for them in their studies. Nevertheless, it does not seem unduly repetitious to restate them:

(1) Diagnosis of species should, in general, not be based upon minor differences in only one or two morphologic characters. Such differences, when used, should be considered taxonomically significant only after careful evaluation involving the study of many specimens. Extensive statistical analysis is not necessary for such evaluation.

(2) Study of the ontogenetic development of conodonts should be emphasized. Müller (1956b, p. 1331) suggested that this would permit the selection of more useful diagnostic criteria which remain relatively constant throughout all growth stages. Most workers have paid scant attention to this aspect of conodont research, with the result that many species are based upon characteristics found only in mature or even gerontic forms.

(3) Description of new conodont species should include a notation of the number of specimens upon which the species is based. Such information increases the responsibility of the original author and gives other workers an indication of how well the species limits are known. Because of the high degree of conodont variability, description of species based on few specimens is viewed as questionable practice. If such specimens merit a formal name, it is reasonable to suppose that additional material can be found. If more specimens are not forthcoming, such rarity in itself indicates the probability that the specimens represent insignificant variants of other species.

(4) The value of adequate illustrations cannot be overestimated. A serious problem confronting workers is the number of new species descriptions published with only one figure for illustration. Re-illustration of the type material of some of the earlier workers would be a welcomed contribution to the conodont literature. At least two different views should be the minimum for even the simplest new forms. Additional figures of common variants and immature specimens are extremely useful and are to be recommended.

(5) At present, certain conodont types such as the "platform" genera of the Devonian and Mississippian (*Palmatolepis*, *Polygnathus*, *Siphonodella*, *Gnathodus*, *Icriodus*, etc.) appear to be our most sensitive time indicators. As data accumulate the usefulness of other conodont types will, of course, also increase greatly. At the risk of overlooking a few stratigraphically useful forms we recommend the description of conodont faunas in which the significant elements, such as the "platform" genera, are described and illustrated in great detail. Such a faunal study is infinitely more useful than one in which multitudes of relatively insignificant forms, such as hindeodellids and lonchodids, are named.

ADDENDUM

Shortly after the present paper went to press, the authors received copies of W. M. Hass' recently published U. S. Geol. Survey Prof. Paper 294-J, "Conodonts from the Chappel Limestone of Texas." In that report (footnote, p. 369), Hass has assigned *Palmatolepis glabra* to the genus *Panderodella* Bassler 1925. He reserves the name *Palmatolepis* for "asymmetric platelike conodonts whose axis is commonly sigmoid in oral view and whose blade is somewhat concave toward the inner platform. In addition, this inner platform is distinctly lobed adjacent to the azygous node; with the lobe so formed commonly built up about a secondary carina and a secondary keel." The author further notes that "*Panderodella* resembles *Palmatolepis*, but its species tend to be narrower and they also lack a distinct lobe on the inner platform.

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NEW SPONGES FROM LOWER CARBONIFEROUS REEFS OF DERBYSHIRE AND YORKSHIRE, ENGLAND

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ABSTRACT—Two new sponges from the Lower Carboniferous of England are described; one represents a new species of *Microspongia* (*Microspongia castletonense* n. sp.) and the other is a new genus (*Radiatospongia carbonaria* n. gen. and n. sp.). The sponges are confined to reef limestone in reef complexes in Derbyshire and Yorkshire.

INTRODUCTION

THIS paper describes the first complete sponges to be found in Lower Carboniferous rocks of England, other than *Erythrospongia* which was considered to be an "unrecognizable supposed sponge" by de Laubenfels (1955, p. 105). Only sponge spicules and occasional small fragments of sponges have previously been described from the English Lower Carboniferous rocks. During a recent investigation of the paleoecology of the mid-Viséan reef complex and shelf limestones of Derbyshire, many complete sponges were found within the reef complex (Wolfenden, 1958, p. 886). The same sponges were also found in the mid-Viséan reef complex of Yorkshire. Two new sponges have been found; one is a new species of *Microspongia* (*Hindia*) and the other a new genus.

The reef limestones within the reef complexes are essentially composed of the *in situ* remains of colonial organisms, of which massive algal deposits of *Collenia-Cryptozoon* type are by far the most important. The sponges are restricted to the reef limestone and are a common, characteristic element of the reef fauna. Rare detrital fragments occur in adjacent facies. In Derbyshire the reefs developed at two horizons and are not continuous either in time or space. They developed at the margin of a shallow shelf and formed an incipient barrier reef which separated the open seas of the English Midlands, in which basin facies limestones were deposited, from a shallow shelf sea. Each reef was elongate parallel to the margin of the shelf and was up to 1200 feet long and averaged 30 feet in width. The reefs accumulated in thicknesses up to 100 feet (Wolfenden, 1958, p. 872). In Yorkshire the detailed field relations of the reefs remain to be worked out; preliminary work by the writer suggests that the reefs developed in a similar manner to those in Derbyshire.

Acknowledgments.—The author is indebted to Dr. S. H. Straw and Dr. I. M. Simpson for encouragement during the research, and gratefully acknowledges the receipt of a grant from the Department of Scientific and Industrial Research. He is indebted to his wife for much assistance during the preparation of the paper.

SYSTEMATIC PALEONTOLOGY

Class DEMOSPONGEA Sollas, 1875
Order LITHISTIDA Schmidt, 1870
Suborder EUTAXICLADINA Rauff, 1893
Family ASTYLOSPONGIIDAE Rauff, 1893
Genus MICROSPONGIA Miller & Dyer, 1878

MICROSPONGIA CASTLETONENSE Wolfenden, n. sp.

Pl. 77, figs. 1,2

Description.—The sponge has a spherical or depressed spherical body with a diameter up to 80 mm., averaging about 50 to 60 mm. The canals (apochetes) are straight, regular, and narrow, and radiate outwards in all directions from the center of the sponge. The canals are circular or polygonal in cross section and have an average diameter of 0.36 mm. The spicular skeleton which forms the walls of the canals is a continuous, open, regular mesh.

State of preservation.—The sponge has been completely calcified with consequent loss of the detailed spicular structure. In some specimens extensive recrystallization has destroyed some of the macroscopic

structures of the sponge.

Discussion.—In general morphology this sponge closely resembles previously described species of *Microspongia*. The species which it most closely resembles is *Microspongia fibrosa* (Roemer) from the middle Silurian, which has a body with a maximum diameter of 45 mm. and canals with an average diameter of 0.3 mm. *Microspongia castletonense* cannot be compared with *Microspongia pumilla* (Hinde), the only other species of *Microspongia* known from the Lower Carboniferous, as the diagnosis of *Microspongia pumilla* was based solely on the form of isolated spicules (Hinde, 1888). *Microspongia castletonense* is considerably larger and has wider canals than other known species.

Localities and horizon.—This species occurs in mid-Viséan reef complexes in which it is confined to the reef. It has been found at Earl Sterndale and Castleton in Derbyshire, and on Cawden Hill, Malham, Yorkshire. It appears to be rare, but as it is exceedingly difficult to distinguish in the field, this may be a false impression, and it is noteworthy that a single block of limestone from Malham contained five individuals.

The reef limestone belongs to the upper *Beyrichoceras* subzone of mid-Viséan (Upper Mississippian) age.

Type.—Holotype (No. T.T.1) collected from Treak Cliff, Castleton, Derbyshire, and paratypes (No. M.1) collected from Cawden Hill, Malham, Yorkshire. Deposited in the Department of Geology, University of Manchester.

Class DEMOSPONGEA Sollas, 1875
Order LITHISTIDA Schmidt, 1870
Suborder ?TETRACLADINA Zittel, 1878
Family ?AULOCOPIIDAE de Laubenfels, 1955
Genus RADIATOSPONGIA
Wolfenden, n. gen.

Description.—The sponge is normally hemispherical and slightly depressed, but some specimens are slightly less regular in shape. The canal system consists of numerous apochetes radiating upwards and outwards from the base, and some prosochetes parallel to the surface of the sponge. A cross section of the sponge, parallel to the base, shows an irregular radial arrangement of the canals and skeletal fibres. No cloaca is present. No dermal layer has been observed near the base of the sponge.

Type species.—*Radiatospongia carbonaria* Wolfenden, n. sp.

RADIATOSPONGIA CARBONARIA
Wolfenden, n. sp.
Pl. 77, fig. 3

Description.—This species has an average diameter of 50 mm., with a maximum of at least 100 mm. Commonly the sponge has a depressed hemispherical body, flattened at the base, with the diameter slightly greater than the height. In longitudinal section, irregular apochetes radiate upwards and outwards from the base, normal to the surface and occasionally branching near the surface. Prosochetes, parallel to the surface of the sponge, are slightly narrower than the apochetes. In cross section the sponge has a characteristic radial appearance; apochetes radiate outwards from the center, and discontinuous prosochetes run concentrically. Between the canals are the skeletal fibres. The apochetes have an average diameter of 1.0 mm. with a range of 0.7 to 1.6 mm. The skeletal fibres are slightly narrower, with an average diameter of 0.4 mm. and a range of 0.3 to 0.7 mm.

State of preservation.—The original skeleton has been completely replaced by a granular mosaic of calcite crystals, and the detailed spicular structure has been destroyed.

Discussion.—*Radiatospongia* shows some resemblance to the Permian genus *Defordia* described by King (1943). The canal system is closely similar to that in the genus *Defordia*, but *Radiatospongia* differs from this genus in the lack of a basal dermal layer and mounds on its upper surface. It differs from the type species of *Defordia*—*Defordia defuncta* King—in the diameter of the canals.

The canal system is characteristic of that in the family Aulocopiidae (de Laubenfels. 1955, p. 52) of the suborder Tetracladina. The sponge is provisionally placed in this suborder and family, but in the absence of spicules this classification is tentative only.

Localities and horizon.—*Radiatospongia* occurs in mid-Viséan reef complexes in which it is confined to the reef, apart from

rare detrital fragments in adjacent facies. The sponge is common at all outcrops of the reef at Castleton and Earl Sterndale, Derbyshire, and in Yorkshire it has been found at High Hills, Settle; Cawden Hill, Malham; and Elbolton Hill, near Cracoe.

The reef limestone belongs to the upper *Beyrichoceras* subzone of mid-Viséan (Upper Mississippian) age.

Type.—Holotype (No. H.H.1) collected from High Hills, Settle, Yorkshire, and paratype (No. T.T.2) collected from Treak Cliff, Castleton, Derbyshire. Deposited in the Department of Geology, University of Manchester.

PALEOECOLOGY

Both sponges are confined to the reef limestone within the reef complex, where they are invariably associated with massive calcareous algae of *Collenia-Cryptozoon* type, encrusting bryozoan colonies (*Fistulipora minor* M'Coy), and encrusting growths of *Chaetetes depressus* (Fleming). This association is absent from the knoll-type reefs of the Bowland area, Lancashire (Wolfenden, 1958, p. 891). These reefs, belonging to the older *Caninia* zone, presumably formed under slightly different conditions. Newell *et al.* (1953, pp. 110–113) recognized an association very similar to that in the Derbyshire and Yorkshire reefs in the Permian reef complex of Texas and New Mexico. In the Permian reefs, sponges—mainly calcareous forms, however—are associated with massive algal deposits and encrusting fistuliporoid bryozoans. It is interesting to to note that some Silurian species of *Microspongia* lived in the reef environment (Lowenstam, 1957, pp. 232–233).

Because of restriction of the sponges to the reef, Newell *et al.* (1953, p. 202) suggested that the sponges "occupied a very limited and specialized habitat near the reef crest in comparatively shallow water." The same conclusion has been reached from a study of these Lower Carboniferous sponges. The ecological factors controlling the distribution of the sponges are not fully known, but an analysis of the reef environment suggests that they lived in shallow, clear, warm, agitated waters, in which oxygen, nutrient salts, and organic foods were quite plentiful (Wolfenden, 1958, p. 890). Recent sponges are often confined to limited habitats; most species require a hard substratum, freedom from covering silt, and have a narrow range of tolerance in regard to salinity and temperature (de Laubenfels, 1957, p. 1083).

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EXPLANATION OF PLATE 77

FIGS. *1–2*—*Microspongia castletonense* Wolfenden, n. sp. Longitudinal sections of the holotype from Treak Cliff, Castleton, Derbyshire. Shows details of radiating canals (compare with figure 45.1, p. 62 of de Laubenfels, 1955). Fig. *1* ×10 approx., and Fig. *2* ×6 approx.

3—*Radiatospongia carbonaria* Wolfenden, n. gen. and n. sp. Longitudinal section of holotype from High Hills, Settle, Yorkshire. Shows apochetes radiating upwards and outwards from the base and discontinuous prosochetes parallel to the surface. Natural size.

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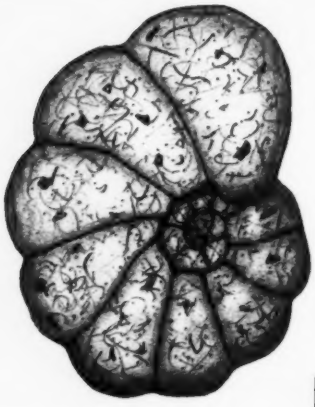

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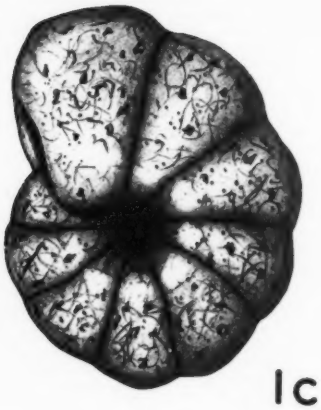

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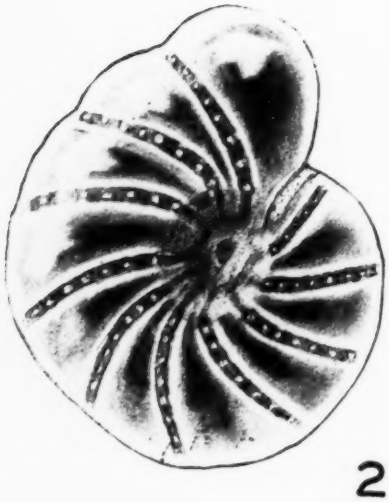

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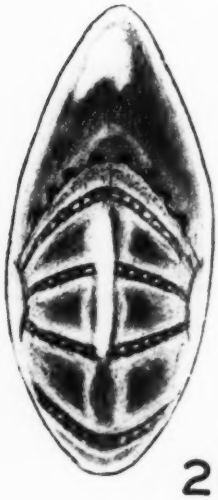

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 569–587, PL. 78, 8 TEXT-FIGS., JULY 1959

FORAMINIFERAL BIOFACIES OFF THE NORTH ASIATIC COAST

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ABSTRACT—A total of 158 bottom samples from the northern Asiatic shelf were examined in order to determine the horizontal and vertical variations in the distribution of the foraminiferal populations. Salinity, temperature, depth, and currents were studied in an attempt to determine the controlling factors in the distribution of the faunas.

It was found that the foraminiferal number, percentage of the planktonic population, and species number increase with depth and distance from shore. The ostracod number, however, was highest near the edge of the continental shelf. A depth stratification of some of the planktonic species was noted.

The arenaceous and porcelaneous populations were most characteristic of depths less than 250 feet, whereas hyaline populations predominate in deeper water.

Five distinct faunal zones were found between the depths of 50 feet to 4400 feet.

Phosphatized Foraminifera and sediments located in the zone of the shelf edge are probably relics of lower sea levels. The degree of preservation of the modern Foraminifera appears to be related to the rate of sedimentation and the length of time exposure.

Depth alone does not appear to be the main control of faunal assemblages. The The Kuroshio Current appears to be a major factor in the final distribution of planktonic forms and possibly those benthonic forms living at depths within the effects of the current. It is probable that salinity, temperature, sediment characteristics, and organic contents are all important ecologic factors.

Two varieties of Foraminifera are described as new.

INTRODUCTION

THE purpose of this study was to determine the vertical and horizontal variation and distribution of Recent foraminiferal biofacies off the north Asiatic coast. Some of the physical factors of the various environments were studied to determine which of these factors might control the distribution of the Foraminifera.

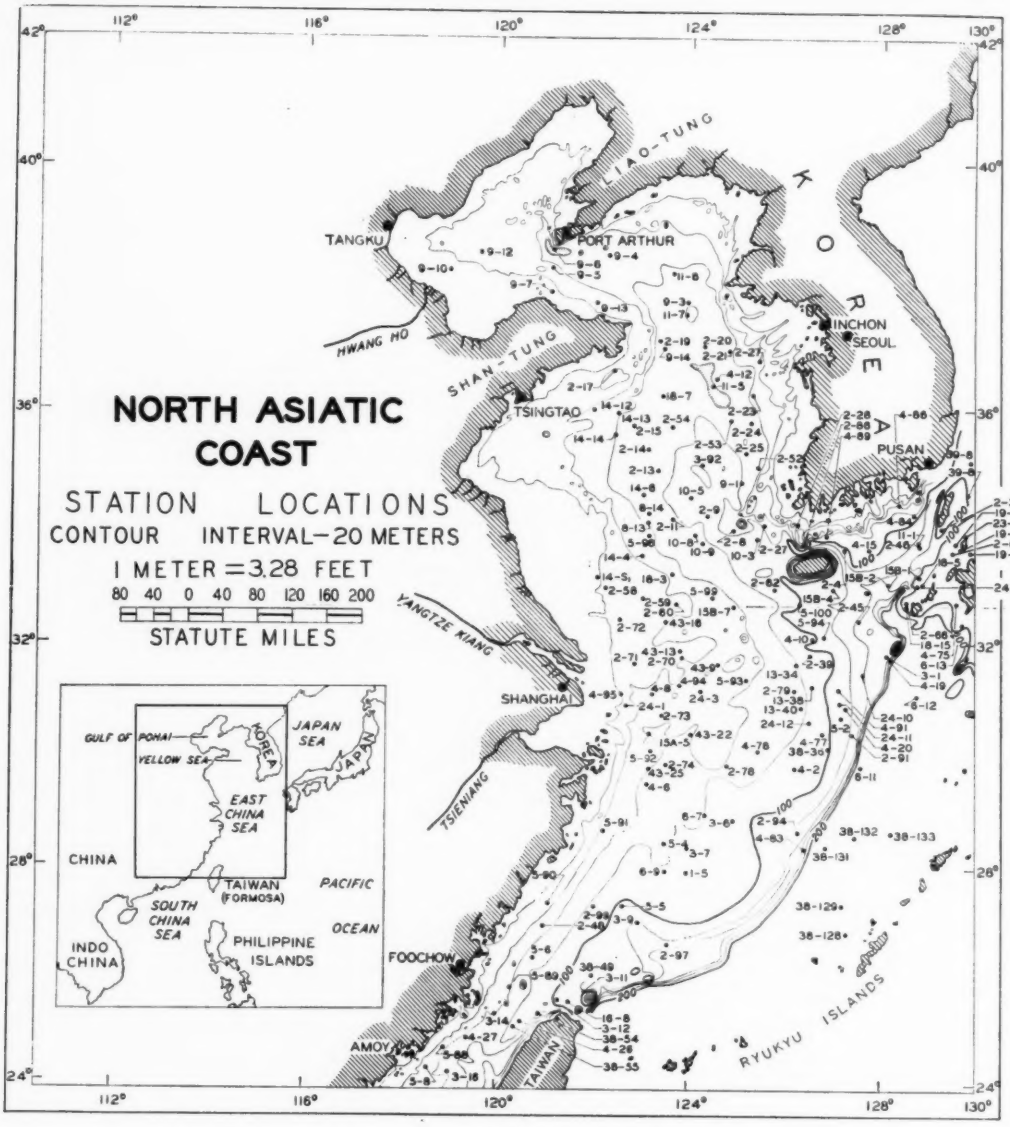
Bottom samples used in this investigation were obtained from Dr. Hiroshi Niino of the Tokyo University of Fisheries. Dr. Niino brought the samples to the Allan Hancock Foundation, the University of Southern California, in 1956 for a joint study of the sediments there with Dr. K. O. Emery. The samples collected from the writer's area totaled over 400 in number, 158 of which were chosen for the present study (Text-fig. 1). Only seven were collected deeper than 200 meters (655 feet), and the deepest sample was taken from the depth of 1,358 meters (4,454 feet).

All samples were collected with small snapper samplers. The material was not preserved or stained, but was dried and stored in small plastic bags. Representative portions of the dried samples were weighed and then washed on a 250 mesh Tyler screen (0.061 mm. openings). A flotation method employing carbon tetrachloride was used to concentrate the Foraminifera and other

EXPLANATION OF PLATE 78

FIG. 1—*Arenoparrella mexicana* (Kornfeld) var. *asiatica* Polski n. var., ×106: a, dorsal view; b, edge view; c, ventral view.

2—*Elphidium discoidale* (d'Orbigny) var. *asiaticum* Polski, n. var., ×300: a, side view; b, edge view.



TEXT-FIG. *1*—Map showing station locations off the north Asiatic coast.

microorganic debris in those samples which had only a few specimens per gram of sediment. The heavy residues were checked to be certain of a complete separation of the fauna. Samples with a large faunal population were split to a convenient size using an Otto microsplitter (1933). The percentage of each species was calculated and only those species amounting to more than three percent in any one sample were considered dominant. Those amounting to less than three percent were not considered in this study.

Extensive bottom sediment work has been completed recently by Shepard, Emery, & Gould (1949), who published a study of the bottom sediment types using data from bottom notation charts based on Japanese observations. A more detailed study by Niino & Emery (1957) dealt with the sedi-

ments of both the north and south Asiatic Shelf.

Cushman (1910, 1911, 1913, 1914, 1915, 1917) reported on a few samples from the area in a taxonomic study of the Foraminifera of the North Pacific. Later Cushman (1921) studied the Foraminifera of the Philippines and adjacent seas. Hada (1929, 1931, 1936a, 1936b, 1937, 1939, 1943a, 1943b, 1955, 1957) examined the Recent Foraminifera around Japan and in the Equatorial Pacific, making ecological interpretations in several of these papers. Asano (1950, 1956a, 1956b, 1957, 1958) has done some taxonomic work on the Foraminifera of adjacent seas of Japan and listed temperature, depth and sediment data but attempted no interpretations.

Additional limited work in ecology and systematics of the Recent Foraminifera around the Japanese Islands has been done by Oinomikado & Stach (1948), Ishiwada (1950), Takayanagi (1953, 1955), and Matsuda (1957). Farther north in the Okhotsk Sea Saidova (1957) made an ecological study of the Recent Foraminifera, incorporating data on depth, temperature, and salinity.

Polski & Waller (1958) reported on an occurrence of a *Gümbelitria* species in the area, and Waller (1958) has carried out an ecologic study of a group of bottom faunas from the South China Sea. This series of samples was also a part of the base collection of Niino & Emery (1957).

The writer is indebted to the following people and organizations for their assistance in this study: Dr. O. L. Bandy of the University of Southern California who suggested the problem and made valuable suggestions and criticisms throughout the investigation; Drs. K. O. Emery and W. H. Easton of the University of Southern California for their helpful suggestions and criticisms of the manuscript; Dr. Hiroshi Niino of the Tokyo University of Fisheries for supplying the samples and other valuable data; the Allan Hancock Foundation of University of Southern California for the use of laboratory and other facilities and Dr. F. P. Shepard of Scripps Institution of Oceanography for supplying valuable data on bottom temperature and salinity.

This study represents Contribution No. 237 of the Allan Hancock Foundation, University of Southern California, Los Angeles, California.

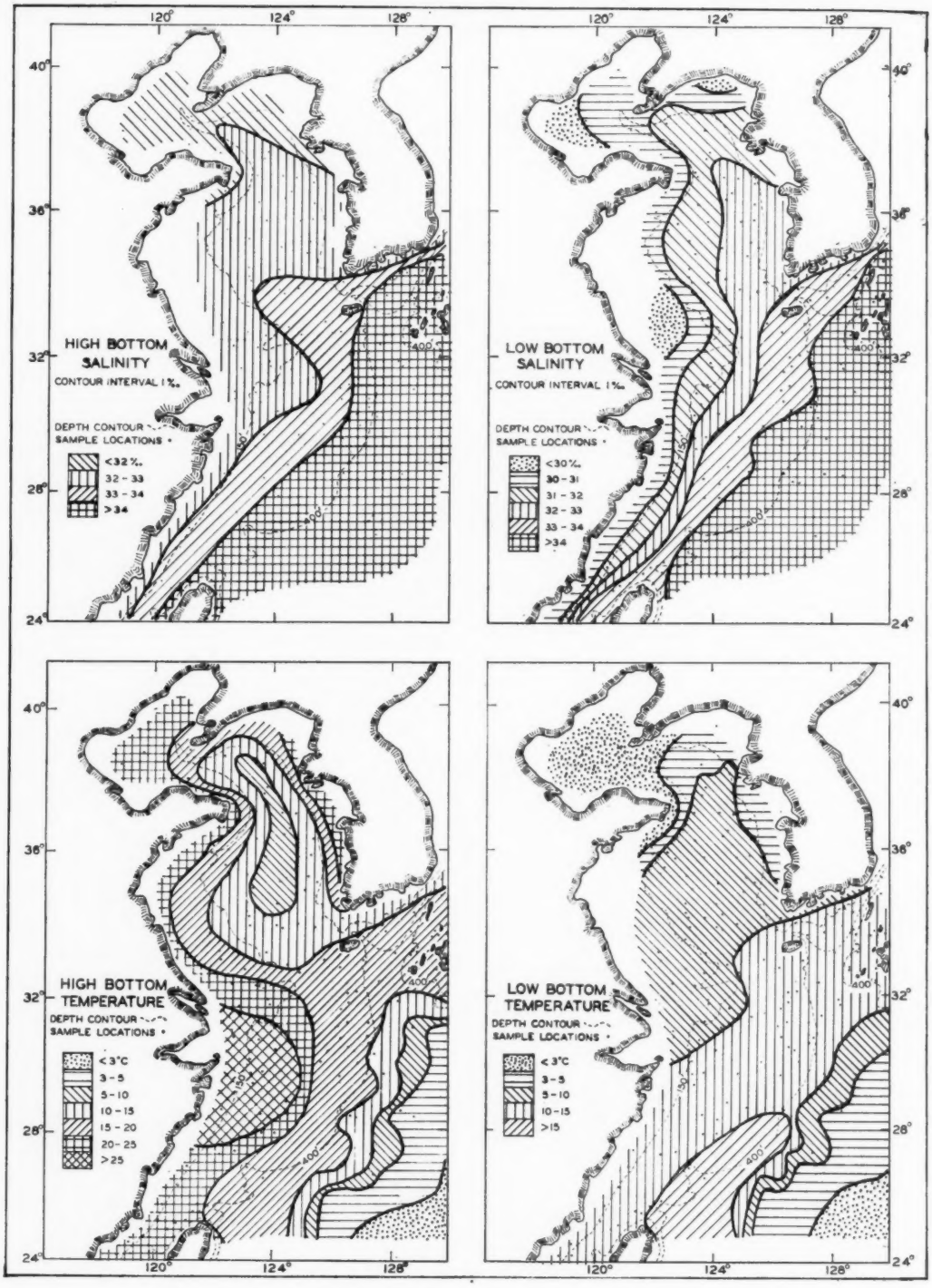
OCEANOGRAPHY

Most of the area under consideration can be classified as continental shelf (Text-fig. 1). The outer edge of the shelf is at a depth of about 400 feet (120 meters) as noted by Niino & Emery (1957). Beyond this depth the bottom slopes more steeply into the Ryukyu Trench which lies between the shelf and the Ryukyu Islands. The widest part of the shelf extends along the axis of Gulf of Pohai, the Yellow Sea and across the East China Sea, a total width of more than 800 miles. The shelf becomes narrower toward the southwest between the China coast and Taiwan where it is still about 100 miles in width.

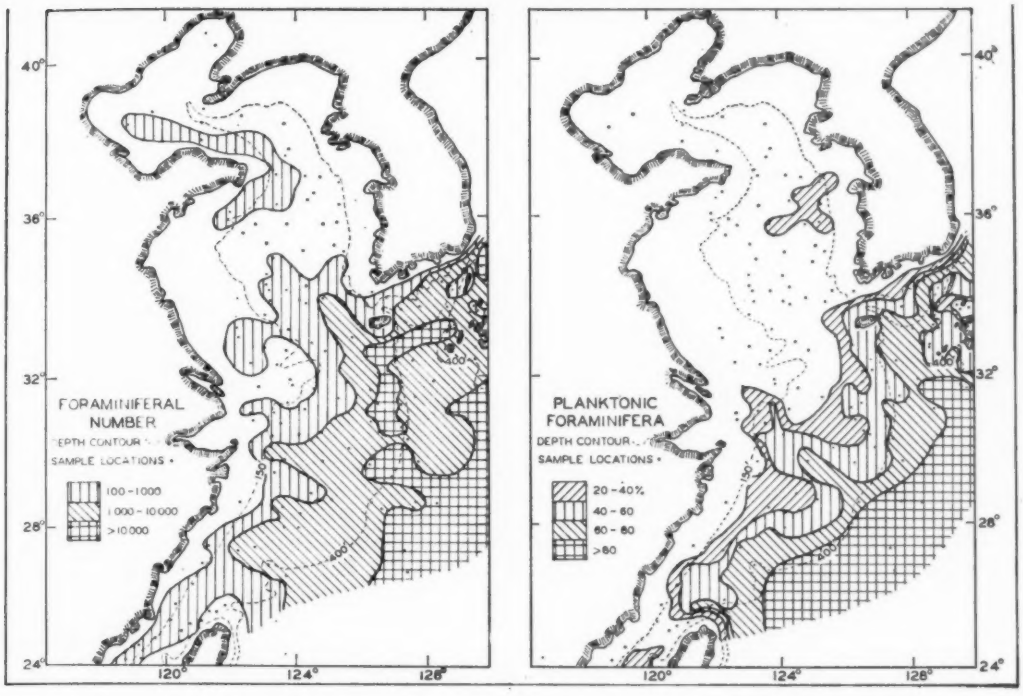
The dominant current in the area is the Kuroshio Current which flows over the outer part of the shelf northeast of Taiwan. This current flows along the outer shelf until it turns toward the east just south of Japan. The Kuroshio carries high temperature, high salinity water from the equatorial regions northward into the colder higher latitudes. During the summer months the current is strongest since the trade wind belt is shifted northward during that season (Niino & Emery, 1957) and causes a stronger deflection of water to pass up the continental coast.

Several branches off the main current are prominent during all seasons. Part of the main Kuroshio flows around the west side of Taiwan and over the shelf north of Taiwan. A well developed branch flows during all seasons through the strait between South Korea and the southwest tip of Japan. A strong branch extends into the Yellow Sea and the Gulf of Pohai during the summer, but this branch is very minor during the winter. Low temperature-low salinity water is carried southward along the coast by a well defined countercurrent that is best developed during the winter season when the Kuroshio is weakest.

The depth of effective motion of the Kuroshio Current has been placed at 700 meters (2,300 feet) by Koenuma (1939). However, the maximum surface velocity is of the order of 4 miles per hour with 2 miles per hour the average (Sverdrup, Johnson, & Fleming, 1942). A current with such a ve-



TEXT-FIG. 2—Areal distribution of maximum and minimum bottom salinities and bottom temperatures.



TEXT-FIG. *3*—Areal distribution of foraminiferal number and planktonic Foraminifera.

locity would certainly be important in the transportation of the planktonic organisms, but its effectiveness as a transporting agent for benthonic organisms is not well known.

The widest ranges in the bottom salinity during an average year can be found in the shallow water near shore (Text-fig. 2). Because of the runoff from large rivers such as the Hwang Ho and the Yangtze, the salinity of waters close to shore does not exceed 33 parts per thousand and may be as low as 29 parts per thousand. A range of two parts per thousand can be expected in the Gulf of Pohai during an average year with a minimum salinity of less than 30 parts per thousand, whereas a range of one part per thousand is normal for the Yellow Sea, which has a minimum of 31 parts per thousand. In the waters of the outer part of the shelf and in the deeper water of the slope, the salinity is fairly constant at about 34 parts per thousand throughout the year.

The greatest annual variation in temperature occurs in the shallow water areas, whereas much more constant temperatures occur in the deeper areas (Text-fig. 2). Typically the range in temperature in the Gulf of Pohai is as much as 22°C. with the highest temperatures greater than 25°C. and the lowest below 3°C. In the central part of the Yellow Sea a range of 10°C. occurs with a high of 15°C. and a low of 5°C. Along the outer shelf the range is also 10°C. with a high of 20°C. and a low of 10°C. The high temperature Kuroshio water is responsible for forming this warm outer shelf water. Deeper water over the slope is fairly constant, with a small yearly range of only 3°C.; the highest temperature is 5°C. and the lowest is less than 3°C.

FAUNAL ANALYSIS

Foraminiferal number.—The foraminiferal number was defined in 1935 by Schott as the total number of foraminiferal specimens, benthonic and planktonic, contained in one gram of dry sediment. The most significant trend exhibited by the foraminiferal number in so far as this study is concerned is an increase with depth and distance from shore (Text-fig. 3). Low values were found in shallow nearshore areas and off the mouths

of large rivers. Rapid sedimentation in these areas dilutes the number of Foraminifera in the sediment, whereas the high values found farther from shore are probably due to the relatively lower rate of sedimentation.

The planktonic population, which is very closely related to the foraminiferal number, contributes greatly to the high foraminiferal number in the offshore area. Shoreward extensions of high values indicate the influence of the branching Kuroshio current which carries planktonic forms.

Off the west coast of Central America the foraminiferal number increases out to the upper part of the continental slope and then decreases in deeper water (Bandy & Arnal, 1957). In the Asiatic area there is a steady increase with depth beyond the upper slope area, possibly because of the transportation of planktonic Foraminifera over this area by the Kuroshio Current.

Planktonic population.—It has recently been demonstrated that not all planktonic Foraminifera live in the surface water, but that a definite depth stratification is present in the water column (Schott, 1935; Phleger, 1945, and Emiliani, 1954). The stratification of living specimens in the water column produces a similar zoning in the bottom sediments. A general depth stratification was noted in the sediments of the north Asiatic region with the following species occurring most abundantly in the sediments below the depths noted:

	Feet
Globigerina bulloides d'Orbigny	150
Globigerina subcretacea Lomnicki	200
Globorotalia trigonula (d'Orbigny)	200
Pulleniatina obliquiloculata (Parker & Jones)	260
Globorotalia menardii (d'Orbigny)	300
Globigerina quinqueloba Natland	300
Tinophodella ambitacrena Loeblich & Tappan	300

The planktonic population was measured in terms of a percentage of the entire foraminiferal population in each sample. In all other instances in this study, the planktonic population is treated as a separate group, as compared to the benthonic population.

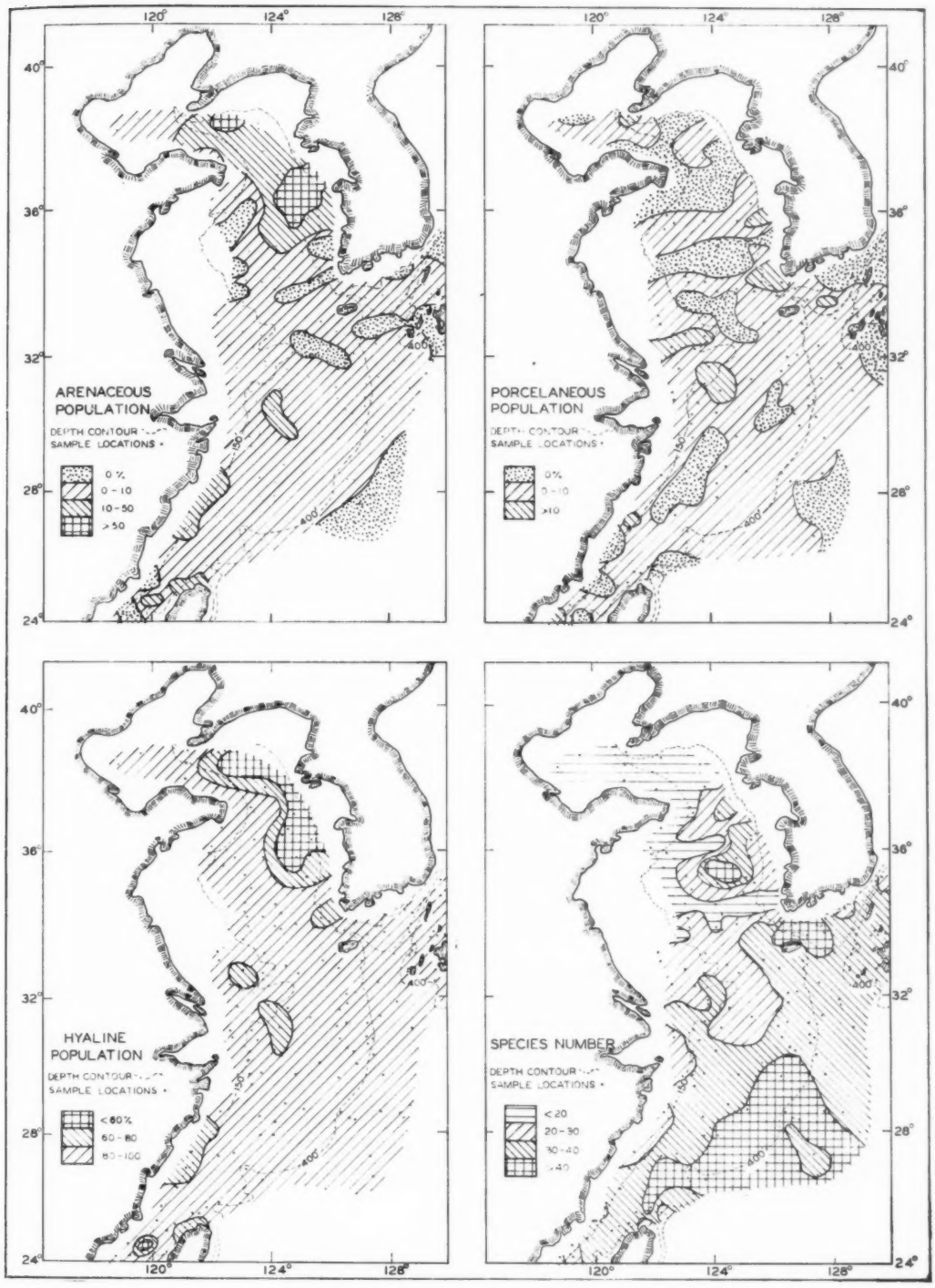
The low percentage values in the shallow water areas are probably due to the stratification of the planktonic species (Text-fig. 3). Waters of the Yellow Sea and the coastal areas are of low density and, consequently, are below the specific gravity of the planktonic species which ordinarily live in the upper part of the surface water layer. The relatively low percentages of the planktonic population in shallow water might also be due to the greater productivity of benthonic species in the shallow water areas, as indicated by Walton's work in Todos Santos Bay (1955). Higher values are found in deeper water since more specimens are present in the water column over the bottom, and find final resting places there. Lower productivity of benthonic forms in the deeper colder water may also be a factor.

According to Waller (1958) the following planktonic species are restricted to the colder waters of the north Asiatic region: *Globigerina bulloides* d'Orbigny, *Globigerina dutertrei* d'Orbigny, *Globigerina gibba* d'Orbigny, *Globorotalia trigonula* (d'Orbigny). An increase in the number of small, presumably juvenile, forms was also noted in the colder northern waters.

Coiling directions of some of the planktonic species were tabulated in an attempt to determine whether changes in coiling direction take place in the area. Distinct provinces could not be defined on the basis of the coiling direction as was done earlier by Ericson, Wollin, & Wollin (1954) for planktonic forms in the Atlantic; probably because a larger area should be investigated. Following the convention suggested by Bolli (1950), rotaloid specimens which add their chambers in a clockwise direction if viewed from the dorsal side are said to be dextral, or right-handed. Throughout the area, *Pulleniatina obliquiloculata* and *Globigerina subcretacea* were found to coil dextrally and *Globorotalia menardii* and *Globorotalia trigonula* coiled sinistrally. All other planktonic species coiled about equally to the right and left.

Benthonic Foraminifera.—The highest percentage of arenaceous Foraminifera occurs in the northeast portion of the Yellow Sea where it makes up as much as 84 percent of the entire population (Text-fig. 4). Those samples with values greater than 10 percent occur shallower than 250 feet, whereas smaller percentages are found in the deeper areas. This pattern is in fairly good agreement with percentages computed by Bandy & Arnal for Central American profiles (1957).

The reason for the concentration of



TEXT-FIG. 4—Areal distribution of arenaceous population, porcelaneous population, hyaline population, and species number.

arenaceous Foraminifera in shallow water is not yet fully understood. The areas of high arenaceous percentage have a predominantly sandy bottom which, according to Hada (1957), should not be a desirable habitat for the arenaceous forms. Conditions such as salinity, temperature, and sediment type may be individually important, or possibly the combined effects of all these may be the controlling factors.

Those species which contributed most to the areas of high percentage are: *Arenoparrella mexicana* var. *asiatica* Polski, n.var., *Eggerella advena* (Cushman), *Saccammina atlantica* (Cushman).

Several of the more important arenaceous species show a generalized depth preference. These are as follows:

Species	Depth in Feet
Arenoparrella mexicana var. *asiatica* Polski, n. var.	62–161
Eggerella advena (Cushman)	62–266
Saccammina atlantica (Cushman)	128–275
Textularia foliacea var. *oceanica* Cushman	134–266
Bigenerina textularioides (Göes)	200–390
Spiroplectammina atrata (Cushman)	268–656

The depth range of *Saccammina atlantica* is in close agreement with the living range (120 to 240 feet) reported by Walton (1955). Bandy, however, found this species in a depth range of from 69 to 141 feet in the Gulf of Mexico (1956, charts 3 and 4). *Eggerella advena* was found living in depths of 30 to 300 feet by Walton (1955). *Bigenerina textularioides*, however, was found by Colom (1950) in the eastern Atlantic from 300 to 1,000 feet, and by Parker in the Gulf of Mexico to be as deep as 600 feet (1954).

The porcelaneous Foraminifera are most abundant in the depths less than 200 feet and occur in small, widely separated areas (Text-fig. 4). Low values, usually less than 4 percent, are scattered over the shelf and down the slope.

Bandy & Arnal (1957) noted a marked increase in the porcelaneous population nearshore, particularly in depths less than 30 feet. High percentages of porcelaneous species were found in depths of less than 100 feet in the Gulf of Mexico (Bandy, 1956).

Those species which were found to be most abundant in the high percentage areas in the north Asiatic region are: *Quinqueloculina lamarckiana* d'Orbigny, *Quinqueloculina akneriana* d'Orbigny, *Sigmoilina arenarea* (Brady).

Two species were found to be restricted in depth. These were: *Quinqueloculina lamarckiana* d'Orbigny, 85–223 feet depth, and *Scutuloris tegminis* Loeblich & Tappan, 197–515 feet depth.

Phleger & Parker (1951) and Bandy (1956, charts 1–7) reported *Quinqueloculina lamarckiana* at depths of less than 300 feet in the Gulf of Mexico.

An inverse relationship exists between the distribution of the hyaline population and the arenaceous-porcelaneous population (Text-fig. 4). The areas in which the percentages of the hyaline species are less than 80 are the areas of high arenaceous and/or porcelaneous percentages. Hyaline percentages greater than 80 are characteristic of the central and outer shelf as well as down the slope.

Some discrepancies were found as regards the depth ranges of some hyaline forms. The depth ranges are generally shallower than had previously been reported by other workers.

The depth ranges of some of the deeper water species listed above agree with the observations noted in other parts of the world except off the California coast where their depths are much greater. *Amphistegina lessonii* was found most abundantly at a depth of about 80 feet off the southwestern tip of Japan. Associated with this species were *Gypsina globula* (Reuss), *Homotrema rubra* (Lamarck) and *Elphidium craticulatum* (Fichtel & Moll).

Neorotalia ozawai (Asano) occurred in the faunas of only five samples where it comprised less than 3 percent of these samples at a depth of less than 207 feet in all instances. The preservation of this species in all samples was poor; specimens were broken, replaced, or of a chalky texture. Asano (1951, pt. 14) originally described this species from the Pliocene of Japan. Because of the poor preservation and the sporadic occurrence in shallow water, the species is believed to be fossil.

Species number.—The number of species of benthonic and planktonic Foraminifera in each sample is defined as the species number of that sample. A general increase in

TABLE 1. DEPTH RANGES OF HYALINE FORAMINIFERA

Species	Depth in Feet	
	North Asiatic Coast	Other
Bolivina acutula Bandy	75–207	147–450 (Bandy & Arnal 1957)
Amphistegina lessonii d'Orbigny	82–230	170–350 (Bandy, 1956)
Uvigerina tenuistriata Reuss	379–407	400–700 (Bandy, 1953)
Epistominella exigua (Brady)	62–4,454	722–3,149 (Parker, 1954)
Nonion barleeanus (Williamson)	2,000–4,454	8,000–12,000 (Bandy, 1953)
Pullenia bulloides (d'Orbigny)	2,000–4,454	4,000–7,500 (Natland, 1957)
Uvigerina proboscidea Schwager	3,805	5,160–8,340 (Crouch, 1952)
Bulimina rostrata Brady	2,542–4,454	4,000–7,500 (Natland, 1957)

the number of species away from shore is recognized off the north Asiatic region (Text-fig. 4). This same trend has been noted previously by Bandy in the Gulf of Mexico (1956). Bandy & Arnal (1957) found an increase in species number with increasing distance from shore out to the upper part of the continental slope after which the number decreased into deeper water. This decrease was not observed in the Asiatic profiles because the investigation did not extend into the deeper waters.

Species analysis.—A faunal analysis was made by comparing the cumulative percentages of the benthonic Foraminifera occurring in particular areas within five given depth ranges (Text-fig. 5). Areal distributions of these faunas were considered in four geographical areas:

(A) The Yellow Sea.
(B) Off South Korea and Southwest Japan.
(C) The East China Sea.
(D) The Taiwan Strait.

Three general faunal types were examined and defined as follows:

(1) The *Restricted Fauna* consists of those species which are found abundantly in only one area and one depth zone.

(2) The *Semicosmopolitan Fauna* is made up of those species which are found in more than one depth zone but not abundantly in all the depth zones.

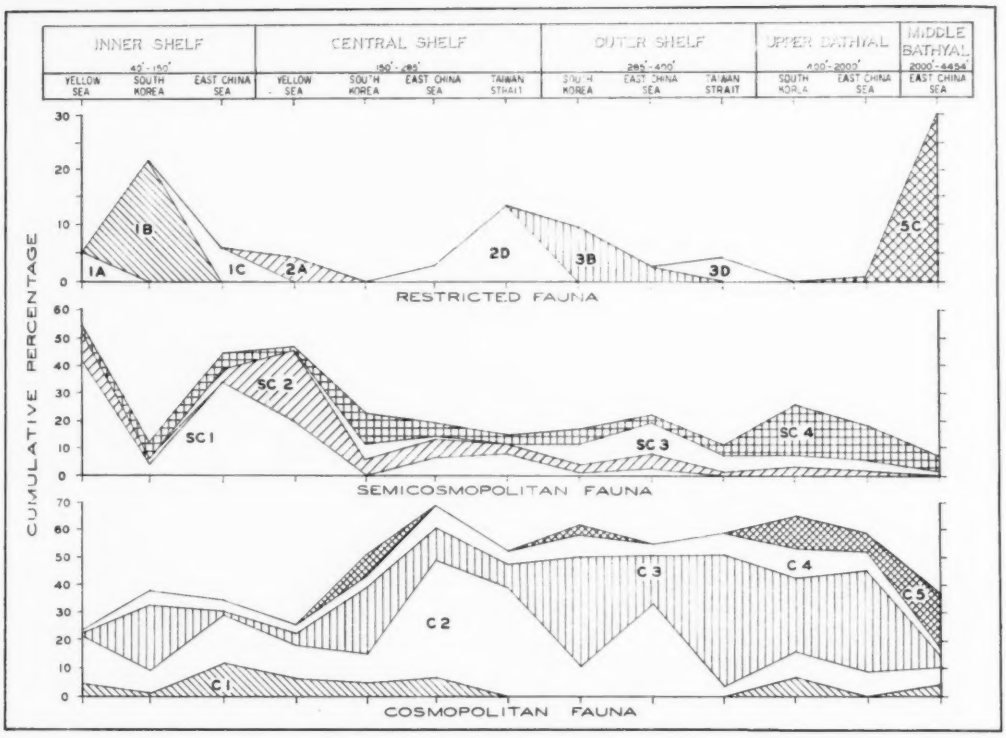
(3) The *Cosmopolitan Fauna* consists of species which occur abundantly in all or nearly all depth zones.

All the species and percentages used in compiling Text-figure 5 are also contained in Text-figure 6 along with data on sediment type.

Five dominant bathymetric faunas were found to be separable. These are as follows:

(1) *Inner Shelf Fauna* (Text-figs. 6 and 7) occurs in the depth range from 49 to 150 feet, salinity of 30 to 34 parts per thousand, and temperatures of 3 to 25°C.

(A) *Yellow Sea Fauna.—Elphidium subincertum* Asano and *Streblus annectens* (Parker & Jones) are restricted to this zone together with abundant occurrences of *Elphidium tsudai* Chiji & Nakaseko, *Streblus beccarii* var. *tepidus* (Cushman) and *Arenoparrella mexicana* var. *asiatica* Polski, n. var. Although it extends into deeper water, this fauna is doubtless similar to the *Elphidium-Streblus* fauna of the Gulf of Mexico (Bandy, 1954).



TEXT-FIG. 5—Composite frequency distribution of the foraminiferal faunas related to depth zones.

(B) *South Korean Fauna.*—Restricted forms in this fauna area: *Cibicides lobatus* (d'Orbigny), *Elphidium fax* Nicol, *Amphistegina lessonii* d'Orbigny, *Bolivina spathulata* (Williamson), and *Poroeponides cribrorepandus* Asano & Uchio.

(C) *East China Sea.—Nonionella tredeca* (Asano) and *Quinqueloculina lamarckiana* d'Orbigny are the important restricted species of the area. As was found in the Yellow Sea Fauna, *Elphidium tsudai* Chiji & Nakaseko and *Streblus beccarii* var. *tepidus* (Cushman) occur abundantly. Shallow water occurrences of *Bolivina robusta* Brady and *Bulimina marginata* d'Orbigny reflect the proximity of open ocean conditions.

The components of the Inner Shelf Fauna usually form from 30 to 50 percent of the species found in depths of less than 150 feet (Text-fig. 7). Parts of the semicosmopolitan and cosmopolitan fraction of the fauna are distributed through the other depth zones, but usually these do not amount to more than 30 percent.

(2) *Central Shelf Fauna* (Text-figs. 6, 7) is confined in the depth range from 150 to 285 feet, salinity of 31 to 34 parts per thousand, and temperature of 5 to 25°C.

(A) *Yellow Sea Fauna.—Saccammina atlantica* (Cushman) is the only restricted species in this fauna.

(B) *South Korean Fauna.*—No species appear to be restricted to this fauna although *Hanzawaia bertheloti* (d'Orbigny) is most abundant here.

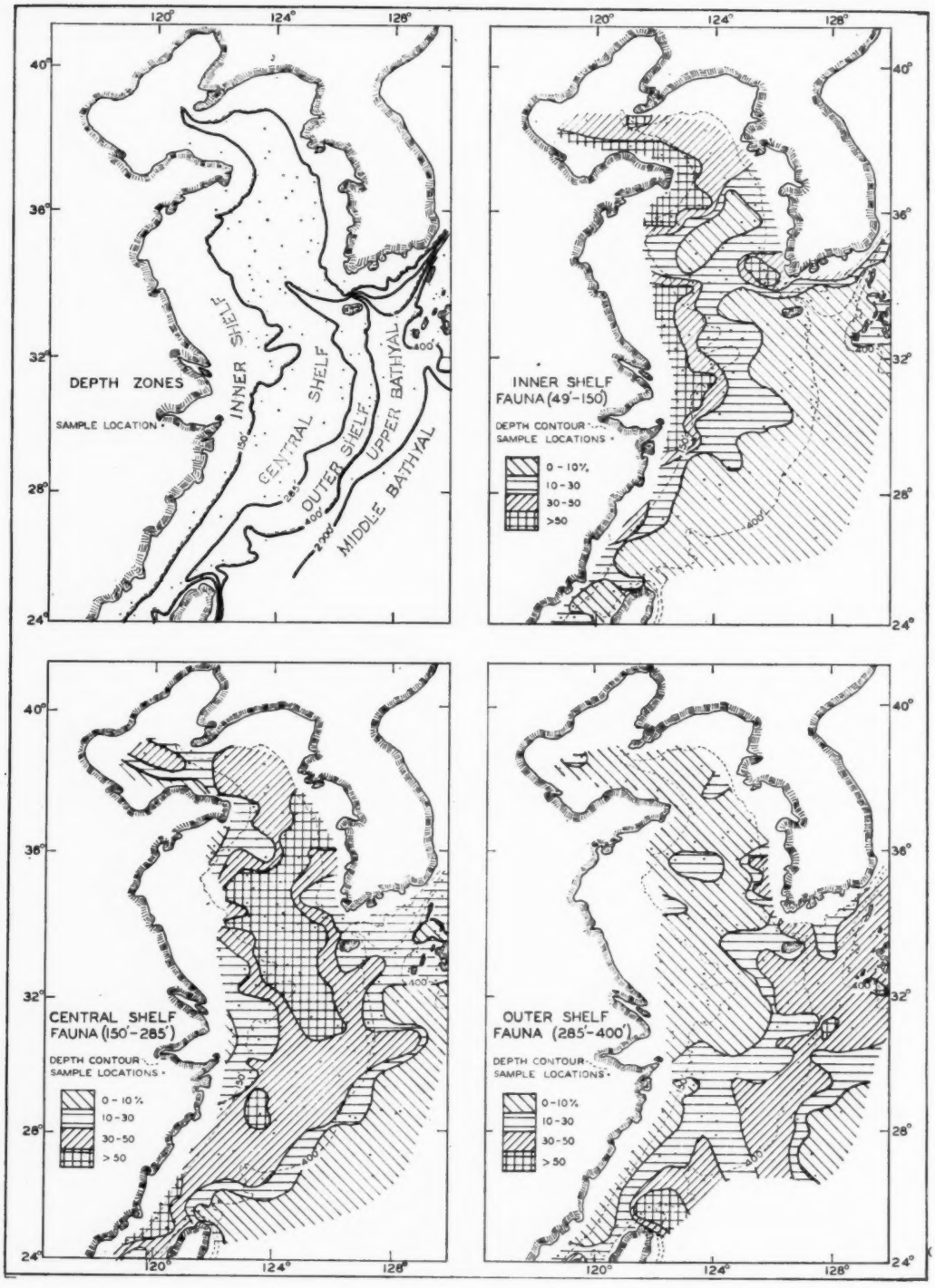
(C) *East China Sea Fauna.*—No species are restricted to this fauna, however, *Streblus compressiusculus* (Brady), a cosmopolitan species, is found most abundantly in this group.

(D) *Taiwan Strait Fauna.*—Five species restricted to this fauna are *Bigenerina textularoides* (Göes), *Bolivina bassensis* Parr,

TEXT-FIG. 6—Average percentage of the dominant species in relation to depth zones, areas and sediment types.

DEPTH RANGE	49-150'						150-265'								265-400'						400-2000'				2000-4454
DEPTH ZONE	INNER SHELF						CENTRAL SHELF								OUTER SHELF						UPPER BATHYAL				MIDDLE BATHYAL
AREA	YELLOW SEA		SOUTH KOREA		EAST CHINA SEA		YELLOW SEA		SOUTH KOREA		EAST CHINA SEA		TAIWAN STRAIT		SOUTH KOREA		EAST CHINA SEA		TAIWAN STRAIT		SOUTH KOREA		EAST CHINA SEA		EAST CHINA SEA	
SEDIMENT TYPE	Sand	Mud	Cal Sand	Sand	Sand	Mud	Sand	Mud	Sand	Mud	Sand	Mud	Sand	Mud	Cal Sand	Sand	Sand	Mud	Sand	Mud	Sand		Sand	Mud	Sand	Mud
RESTRICTED FAUNAS																										
FAUNA 1A																										
ELPHIDIUM SUBINCERTUM	1.1	3.5					.7	.2			.2															
STREBLUS ANNECTENS	3.1	3.3					1.1	.6			.1		2.0				.3						.1			
FAUNA 1B																										
CIBICIDES LOBATUS	.2		6.0	.7			.2		.8				.7				.1									
ELPHIDIUM FAX			1.0	4.0					.8																	
AMPHISTEGINA LESSONII			1.0	20.7					.2																	
BOLIVINA SPATHULATA				3.3		.5							.1	.5		.3	.1									.3
POROEPONIDES CRIBROREPANDUS			2.7	4.0				.1											.5				.9	1.0		
FAUNA 1C																										
NONIONELLA TREDECA		.3			4.6	1.5	.2		.2	1.0	1.0	1.4	2.4				.1		.5							
QUINQUELOCULINA LAMARCKIANA	1.4	1.5			1.9	4.0	.8	.7			.8	.8	.1	.5		.3	.4				.3		.5			
FAUNA 2A																										
SACCAMMINA ATLANTICA	2.9						5.1	4.4					.1													
FAUNA 2D																										
BIGENERINA TEXTULARIOIDES											.5		6.0				.5									
BOLIVINA BASSENSIS											.1		3.0													
TEXTULARIA SECASENSIS	.1		2.3	1.7							.1		7.1						1.5	2.0			.2			
GÜMBELITRIA VIVANS					.1	1.5	.1			.7	1.2	1.0	.7	6.0		.6	.3						.3			
PLANULINA ELEGANS					.5	1.0		.1		1.3	1.4	1.6	.3	4.5		.6	.8	1.0	1.0				.3	2.0		
FAUNA 3B																										
LOXOSTOMUM AMYGDALAEFORME				.7					.4						4.0											
CIBICIDES DEPRIMUS				.3			.1		1.2		.2				5.0	.8	2.8		.5	2.0					1.0	
BOLIVINA OVATA						1.5					1.0				7.0	3.0	1.0	1.7					1.2		.5	.3
FAUNA 3D																										
STREBLUS INDOPACIFICUS											.1	.6					1.1	.3		9.0						
FAUNA 5C																										
BULIMINA ACULEATA																									5.0	
CASSIDULINA PACIFICA																									4.5	.3
CIBICIDES WÜLLERSTORFI																.1	.1						2.4		5.0	
EPONIDES TENER VAR. STELLATUS																.3					1.3				5.5	.3
NONION BARLEEANUS																									3.0	6.0
PULLENIA BULLOIDES																									4.5	6.3
"BOLIVINOPSIS" BULBOSA																									.5	5.7
BULIMINA ROSTRATA																									.5	3.3
BOLIVINA PSEUDOPLICATA							.1	.1																		12.7
ANGULOGERINA ANGULOSA																		.3							.5	6.3
SEMICOSMOPOLITAN FAUNAS																										
FAUNA SC 1																										
ELPHIDIUM TSUDAI	15.1	39.4		.3	3.9	10.0	16.4	10.9			.8					.8					.7					
QUINQUELOCULINA AKNERIANA	1.6		3.3		.7	3.0	.3	1.6	.6				.6			.8	.4				1.0		.1			
STREBLUS BECCARII VAR. TEPIDUS	11.1	10.2			17.1	13.5	4.3	2.9			2.2	.4	2.3	3.5		.1	.1	2.7	.5							
SIGMOILINA ARENARIA	2.9	.3	.3	.7	4.6	1.5	.2	2.0	.4		2.5	1.0	4.0			.3	.9	.7					1.5		.5	
HANZAWAIA SUMITOMOI						5.0					.8	.8	.6	4.5												
ARENOPARRELLA MEXICANA VAR. ASIATICA	2.9	1.0			2.4	5.0	.3	.6				4.8														
FAUNA SC 2																										
BUCCELLA FRIGIDA	3.4	3.3	.7				4.9	2.0	4								.1									
EGGERELLA ADVENA	6.9	.3			1.7		15.5	4.6																		
ASTRONONION ITALICUS	4.0	1.6	1.7		.9	2.0	7.7	10.0		1.7	2.0	3.0	.3	1.5		.1	.5	1.3	.5	2.0	.3					
HANZAWAIA BERTHELOTI			.7	.7	.5			.1	2.2	6.7	.6		.7		1.0	4.0	1.6	.7			3.0		.4	3.0	1.0	
BUCCELLA NAKAMURAI	1.7	2.3			3.7		3.6	3.2	.2	1.0	2.4	4.0	1.3	3.5			1.5	4.0			0.3		.4			
FAUNA SC 3																										
EPONIDES PUSILLUS	.1							.1	3.8	2.0	1.0				5.0	7.1	5.2	13.0			1.7		2.1			3.0
SPIROPLECTAMMINA ATRATA			.7	.3			.2	.1	3.0	.7	1.0	.6				2.3	2.5	.5	2.5	9.0	2.3		4.4	2.0		
FAUNA SC 4																										
ELPHIDIUM ADVENUM	3.4	3.5	2.3	2.7	1.1	2.5	1.0	.5	4.2	3.7	2.3	6.2	1.6	4.5		3.4	2.3	1.3	.5	2.0	10.4		1.5	9.0	.5	
SCUTULORIS TEGMINIS		2	7	.7	6		.7		2.2	3.7	.1		.1			2.1	.3		1.5		4.3		1.0	3.0		.3
CIBICIDES PSEUDOUNGERIANUS			1.0	4.0			.1		4.6	1.0	.1	.2				2.1	.1		1.0	2.0	1.7		7.9	1.0	1.5	1.0
HÖGLUNDINA ELEGANS			.3	.3			.2	.1	4.0	.7					2.0	.6	.8				1.7		1.0		6.0	1.3
COSMOPOLITAN FAUNAS																										
FAUNA C1																										
EPISTOMINELLA EXIGUA	4.0	5.0	2.0		11.1	13.5	7.1	7.4	2.0	7.7	6.5	7.8	.3	.5		3.1	1.0	.7		2.0	7.0		.9		3.0	5.7
FAUNA C2																										
STREBLUS KETIENZIENSIS	6.4	1.0	2.0	1.0	1.1		7.1	15.5	2.2	2.3	3.5	5.8	1.4	4.5	2.0	4.3	2.0	.3	.5		1.0		2.2		.5	
STREBLUS COMPRESSIUSCULA	6.4	4.8		6.0	5.5	5.5	2.9	1.9	1.4	1.0	7.7	16.2	4.4	4.0		.7	3.8	.6	5.0				1.0			
BOLIVINA ROBUSTA	3.2	2.6	5.7	2.0	13.6	8.0	2.4	3.2	7.2	8.0	21.1	29.8	24.1	39.0	6.0	9.5	22.0	37.3	.5	2.0	8.0		11.6	5.0	11.0	1.3
FAUNA C3																										
CASSIDULINA LAEVIGATA VAR. CARINATA	.2		1.3	.3	1.7	.5	.3	1.8	3.0	8.0	4.8	4.0	1.4	1.5	19.0	11.3	9.2	7.3	2.0	2.0	10.0		8.3	9.0	5.0	2.0
UVIGERINA AUBERIANA	.1		.3		.2		.6	.4	3.8	6.3	2.1	3.2	.7	.5	7.0	5.0	5.6	4.7	1.5	2.0	6.3		3.2	6.0	.5	.7
ROTORBINELLA VERSIFORMIS	.1	.2	4.3	5.7	.2		.8	.5	4.0	5.7	1.2	.6	8.0		18.0	6.0	1.4	2.0	4.0		5.3		1.8	16.0		.7
CIBICIDES HAIDINGERI VAR. PACIFICA	.5	.8	24.3	10.0	.1		1.5	3.0	13.8	4.3	4.6	3.6	4.2	1.0	2.0	10.4	6.2		49.5	34.0	4.9		22.0	9.0	.5	
HANZAWAIA NIPPONICA																										
FAUNA C4	1.0	.3	2.3	7.3	.4		.8	3.3	2.6		2.2	1.6	5.0	1.0	3.0	.7	1.1		6.0	9.0	2.3		2.5		2.0	
BULIMINA MARGINATA	4	.3	.3	.3	3.2	5.0	1.0	1.9	2.8	4.0	6.1	7.0	.6	4.5	8.0	5.0	2.8	5.3	1.0		8.7		2.1	11.0	1.0	2.7
FAUNA C5																										
CASSIDULINA SUBGLOBOSA	.2	.7	.3	.3	.5		.5	.8	9.0	6.7	.8	.8			4.0	5.1	1.1	.3	2.5		11.7		4.2	11.0	13.0	24.0

AVERAGE PERCENTAGE OF THE DOMINANT SPECIES



TEXT-FIG. 7—Areal distribution of depth zones, Inner Shelf Fauna, Central Shelf Fauna and Outer Shelf Fauna.

Textularia secasensis Lalicker & McCulloch, *Gümbelitria vivans* Cushman, and *Planulina elegans* (Williamson).

Recently Polski & Waller (1958) demonstrated the central shelf occurrence of *Gümbelitria vivans* by showing its area distribution off the Asiatic coast. This restricted occurrence also helps to establish this species as a benthonic form.

As was found in the Inner Shelf Fauna, the species of the Central Shelf Fauna make up more than 30 percent of the species observed within the depth boundaries (Text-fig. 7).

(3) *Outer Shelf Fauna* (Text-figs. 6, 7) has a depth range from 285 to 400 feet, salinity of 33 to 34 parts per thousand, and temperature of 10 to 20°C.

(B) *South Korean Fauna.*—The restricted species of this fauna are *Loxostomum amygdalaeforme* (Brady), *Cibicides deprimus* Phleger & Parker, and *Bolivina ovata* Egger.

(C) *East China Sea Fauna.*—No restricted species are present in this assemblage.

(D) *Taiwan Strait Fauna.*—*Streblus indopacificus* (Thalmann) is the only species restricted to this fauna.

The percentages of the species of the Outer Shelf Fauna are generally above 30 percent within the depth boundaries of this zone (Text-fig. 7). Some high percentages of occurrence of this fauna overlap downslope into the Upper Bathyal Zone. The overlap is apparently due primarily to the high percentage values of the cosmopolitan species common to both depth zones.

(4) *Upper Bathyal Fauna* (Text-figs. 6, 8) has a depth range from 400 to 2,000 feet, salinity of 34 parts per thousand, and temperature of 7 to 20°C.

(B) *South Korean Fauna.*—No restricted species are present; however, the highest occurrence of *Elphidium advenum* (Cushman) is in this fauna. The abundance of *Elphidium* in this deep zone is in agreement with the findings of Bandy (1954) in the Gulf of Mexico. He found that " . . . *Elphidium* thrives in water of both low and normal chlorinity. One species of *Elphidium* was found only in water of normal chlorinity, indicating that there are different chlorinity tolerances within the genus."

(C) *East China Sea Fauna.*—No restricted species are apparent in this fauna.

The Upper Bathyal Fauna is the least distinctive of the five faunal zones. It is closely related to the Outer Shelf Fauna but is quite unrelated to the deeper Middle Bathyal Fauna. The lack of distinctiveness between the Outer Shelf and the Upper Bathyal Faunas is doubtless due to the influence of the warm saline Kuroshio Current, a current which is most effective over the shelf break and to a depth of about 2,000 feet (Koenuma, 1939). It probably obliterates any sharp faunal break by causing similar environmental conditions, other than depth, in both faunal zones. The deeper Middle Bathyal Zone is not effected by the Kuroshio Current and consequently the faunal characteristics of the two zones are different.

(5) *Middle Bathyal Fauna* (Text-figs. 6, 8) is within the depth range of 2,000 to 4,454 feet, salinity of 34 parts per thousand, and temperature of 3 to 15°C.

(C) *East China Sea Fauna.*—The following ten species are restricted to this faunal group: *Angulogerina angulosa* (Williamson), *Bolivina pseudoplicata* Heron-Allen & Earland, "*Bolivinopsis*" *bulbosa* (Cushman), *Bulimina aculeata* d'Orbigny, *Bulimina rostrata* Brady, *Cassidulina pacifica* Cushman, *Cibicides willerstorfi* (Schwager), *Eponides tener* var. *stellatus* (Silvestri), *Nonion barleeanus* (Williamson), and *Pullenia bulloides* (d'Orbigny).

All the samples of this zone contain radiolarians which increased in abundance with depth. This is similar to what has been found elsewhere (Bandy & Arnal, 1957).

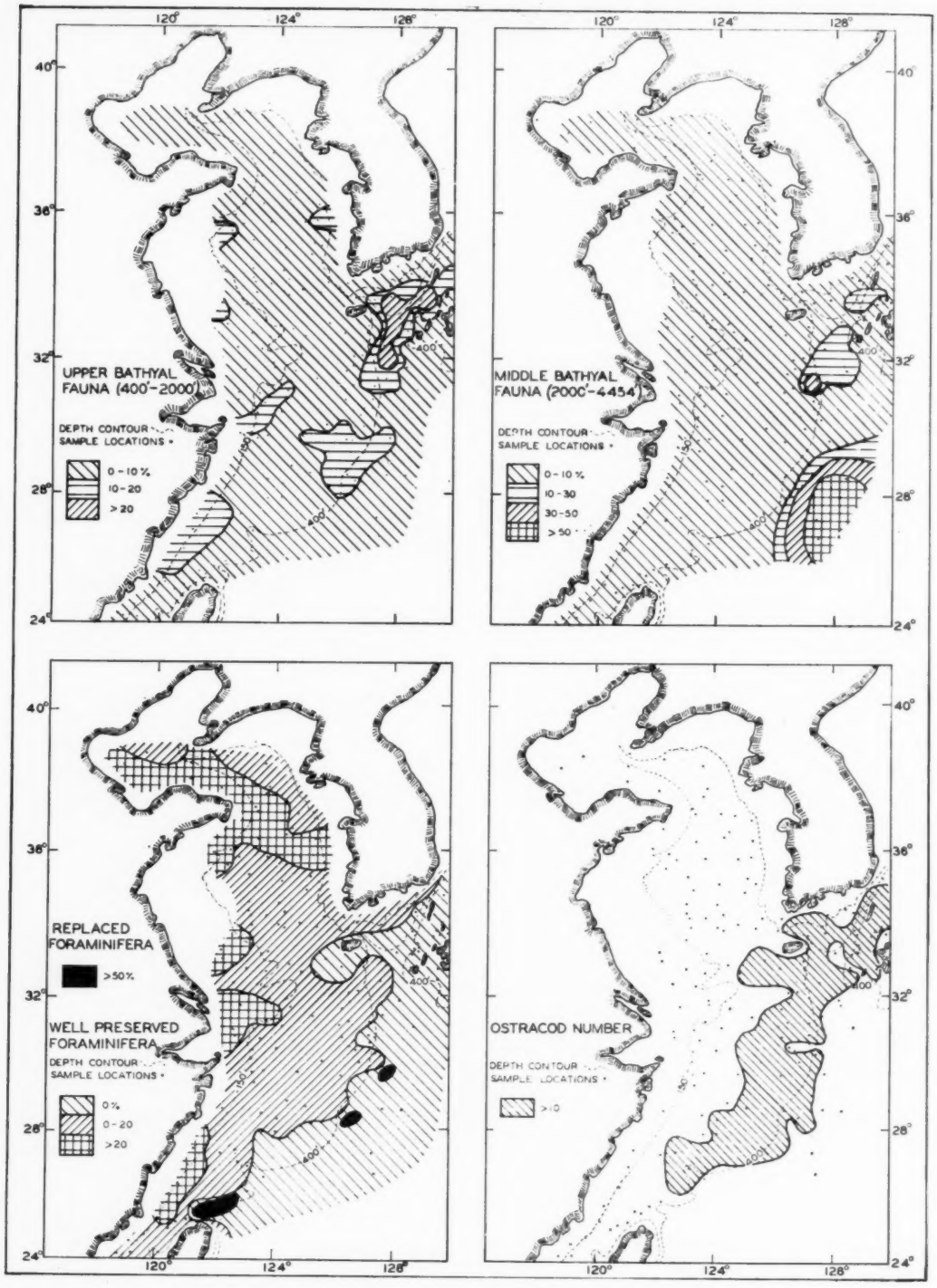
As stated above, the depth ranges of some of these deeper water species are known to occur much deeper off the California coast. The reasons for the difference in depth range is not known.

Sediment type preference.—Several species were found most abundantly in particular sediment types. Major sediment types are: calcareous sand, sand and mud. The list in Table 2 has been compiled from data in figure 6.

Several species which were found in only one sediment type were not listed since they occurred in only a few samples in low percentages.

In a study as broad as the present investigation, some of the occurrences listed above probably were found in only one sediment type purely by chance rather than preference.

Replaced fauna.—Six samples from 334 to 656 feet in depth contained more than 50 percent replaced Foraminifera (Text-fig. 8). The replacement was by phosphorite, determined by chemical test. Most of the replaced species in these samples give the appearance of an Inner Shelf Fauna. Miliolid, arenaceous, and *Streblus* species occur together;



TEXT-FIG. 8—Areal distribution of the Upper Bathyal Fauna, Middle Bathyal Fauna, replaced Foraminifera, well preserved Foraminifera and ostracod number.

TABLE 2. SPECIES SHOWING PREFERENCE FOR CERTAIN TYPES OF SEDIMENT

	Inner Shelf	Central Shelf	Outer Shelf	Upper Bathyal	Middle Bathyal
Calcareous Sand					
Cibicides lobatus (d'Orbigny)	X	X			
Cibicides deprimus Phleger & Parker	X	X	X		
Loxostomum amygdalaeforme (Brady)	X	X	X		
Sand					
Amphistegina lessonii d'Orbigny	X	X			
Eggerella advena (Cushman)	X	X			
Textularia secasensis Lalicher & McCulloch	X	X	X	X	
Höglundina elegans (d'Orbigny)	X	X	X	X	X
Bigenerina textularioides (Göes)		X	X		
Cibicides wüllerstorfi (Schwager)			X	X	X
Eponides tener var. *stellatus* (Silvestri)			X	X	X
Mud					
Hanzawaia sumitomoi Asano & Murata	X	X			
Strebelus indopacificus (Thalmann)		X	X		
"*Bolivinopsis*" *bulbosa* (Cushman)					X
Bulimina rostrata Brady					X

many of these were not found in the Recent faunas of this study. Sand grains, shell fragments and foraminiferal tests were rounded and broken, giving additional evidence for a nearshore deposit. It is believed possible that these six samples were shallower water deposits in an area of nondeposition during a time of low sea level in the Pleistocene.

According to Emery & Dietz (1950), phosphorite on the sea bottom possibly indicates areas of non-deposition and also it is commonly associated with unconformities.

Well preserved Foraminifera.—Specimens which were not broken, altered, or filled were considered well preserved. Well preserved forms were found to be characteristic of inshore waters (Text-fig. 8). High percentages of well preserved Foraminifera were noted adjacent to large rivers and in areas of rapid deposition. Possibly rapid burial prevents a specimen from being exposed to the open environment where diagenetic changes may alter the structure of the test, giving it a chalky appearance. In deep water no abundant species were found preserved as well as those near shore. Deep water species are not buried immediately but may be exposed to the environment for a period of time.

Those species which are most commonly well preserved are:

Bolivina acutula Bandy
Bolivina robusta Brady
Buccella frigida (Cushman)
Bulimina marginata d'Orbigny
Cassidulina laevigata var. *carinata* Silvestri
Elphidium tsudai Chiji & Nakaseko
Epistominella exigua (Brady)
Gümbelitria vivans Cushman
Hanzawaia nipponica Asano
Streblus beccarii var. *tepidus* (Cushman)
Streblus compressiusculus (Brady)

Ostracod number.—The total number of ostracod valves per gram of dry sediment is defined as the ostracod number. Values greater than 10 were found over most of the outer shelf area although some high values extend into other depth zones (Text-fig. 8). In general, the configuration of the areal distribution pattern suggests that the region of high ostracod number is along the main course of the Kuroshio Current. Not enough is known of the ecology of Recent ostracods to determine the causes of such a pattern.

CONCLUSIONS

1. Foraminiferal number increases with depth and distance from shore. No decrease is found beyond the shelf break due to the influence of the plankton-rich Kuroshio current.

2. The planktonic population increases in percentage away from shore. Low density water, high benthonic productivity, and a shorter water column are believed to cause low percentage values near shore. A depth stratification of the planktonic species is

TABLE 3. SPECIES RESTRICTED TO A PARTICULAR GEOGRAPHIC AREA

	Yellow Sea	South Korea	East China Sea	Taiwan Strait
Inner Shelf Zone (49–150 feet)				
Elphidium subincertum Asano	X			
Streblus annectens Parker & Jones	X			
Amphistegina lessonii d'Orbigny		X		
Bolivina spathulata (Williamson)		X		
Cibicides lobatus (d'Orbigny)		X		
Elphidium fax Nicol		X		
Poroeponides cribrorepandus Asano & Uchio		X		
Nonionella tredica (Asano)			X	
Quinqueloculina lamarckiana d'Orbigny			X	
Central Shelf Zone (150–285 feet)				
Saccammina atlantica (Cushman)	X			
Bigenerina textularioides (Göes)				X
Bolivina bassensis Parr				X
Gümbelitria vivans Cushman				X
Planulina elegans (Williamson)				X
Textularia secasensis				X
Outer Shelf Zone (285–400 feet)				
Bolivina ovata Egger		X		
Cibicides deprimus Phleger & Parker		X		
Loxostomum amygdalaeforme (Brady)		X		
Streblus indopacificus (Thalmann)				X
Upper Bathyal Zone (400–2,000 feet)				
No restricted species				
Middle Bathyal Zone (2,000–4,454 feet)				
Angulogerina angulosa (Williamson)			X	
"Bolivinopsis" bulbosa (Cushman)			X	
Bulimina aculeata d'Orbigny			X	
Bulimina rostrata Brady			X	
Cassidulina pacifica Cushman			X	
Cibicides wüllerstorfi (Schwager)			X	
Eponides tener var. *stellatus* (Silvestri)			X	
Nonion barleeanus (Williamson)			X	
Pullenia bulloides (d'Orbigny)			X	

present with *Globigerina bulloides* becoming abundant below 150 feet, *Globigerina subcretacea* and *Globorotalia trigonula* appearing below 200 feet, *Pulleniatina obliquiloculata* at 260 feet, and *Globorotalia menardii*, *Globigerina quinqueloba* and *Tinophodella ambitacrena* occurring abundantly below 300 feet.

3. *Pulleniatina obliquiloculata* and *Globigerina subcretacea* consistently coil to the right whereas *Globorotalia menardii* and *Globorotalia trigonula* coil to the left. All other species coil about equally left and right. No coiling ratio provinces are apparent in the area.

4. The arenaceous and porcelaneous populations are most abundant in depths less than 250 feet. *Arenoparrella mexicana* var. *asiatica*, *Eggerella advena* and *Saccammina atlantica* are arenaceous species found most abundantly in shallow water. The porcelaneous species most abundant in shallow water are *Quinqueloculina lamarckiana*, *Quinqueloculina aknariana* and *Sigmoilina arenarea*. Hyaline population values greater than 80 percent are characteristic of depths greater than 150 feet.

5. Fossil specimens of *Neorotalia ozawaia* were found in local areas.

6. The number of species per sample increases away from shore.

7. Within the different depth zones, the dominant species listed in table 3 are restricted to particular geographic areas.

8. Depth ranges of some of the Middle Bathyal species have been reported much deeper off the California coast.

9. Radiolarians were found to occur

abundantly only at depths greater than 2,000 feet.

10. The most cosmopolitan species in the area are *Bolivina robusta* Brady, *Cassidulina laevigata* var. *carinata* Silvestri, *Uvigerina auberiana* d'Orbigny, *Cibicides haidingeri* var. *pacificus* Cushman and *Bulimina marginata* d'Orbigny.

11. Several species occur abundantly in one particular sediment type. Whether this indicates a preference for an individual sedimentary environment cannot be determined with the data at hand.

12. Phosphorite replacement of six samples along the edge of the shelf are possibly nearshore Pleistocene sediments.

13. Well preserved specimens of Foraminifera are most abundant in the Inner and Central Shelf Zones where rapid burial occurs.

14. Ostracod number is highest along the Outer Shelf Zone where the Kuroshio Current is believed to be related to the ostracod abundance.

SYSTEMATIC PALEONTOLOGY

Family TROCHAMMINIDAE Schwager, 1877
Genus ARENOPARRELLA Anderson, 1951
ARENOPARRELLA MEXICANA ASIATICA Polski n. var.

Pl. 78, fig. 1a–c

Description.—The test is arenaceous, trochoid, and composed of two whorls. The dorsal side is moderately convex with the chambers of the final whorl slightly raised above the surface of the chambers of the previous whorl. The ventral side is involute, with a depressed umbilicus. The periphery is rounded and lobate in the later portion of larger specimens, otherwise it is entire. There are usually 8 to 9 chambers in the final whorl. They are higher than broad, enlarging fairly rapidly in size as added. The chambers on the dorsal side slightly overlap the chambers of the previous whorl. The sutures are indistinct in the early stage, but are distinct later. They are only slightly depressed and are moderately curved on the dorsal side, but are more depressed, nearly radial and straight on the ventral side. The aperture is a round to irregularly elongated opening in the center of the last septal face located in an elongated depression oriented with the long axis parallel to the plane of coiling. The test is composed of medium to coarse grained arenaceous material, yellowish-brown in color with the early portions of the test darker brown than the outer whorl. The diameter is 0.51 mm.; the thickness 0.22 mm.

Remarks.—This variety differs from the typical in having more chambers, the chambers being higher than broad and partly overlapping the chambers of the previous whorl on the dorsal side, and having a smaller aperature in a larger depression.

Anderson (1951, Cont. Cushman Found. Foram. Research, v. 2, pt. 3, p. 96) emended the genus *Arenoparrella* on the basis that he found what he felt was supplementary apertures at the apex of the final chamber. None of the specimens of the new variety show any indication of such supplementary apertures.

Type figure.—Pl. 78, fig. 1a–c, holotype, ×106: a, dorsal view; b, edge view; c, ventral view.

Locality.—Sample 2–59, latitude 32° 43′ N, longitude 123° 04′ E, depth 105 feet, muddy sand bottom. Southwestern Yellow Sea, Asiatic coast.

Age.—Recent.

Holotype and paratypes.—U.S.C. Nos. 4909 and 4910.

Family NONIONIDAE Reuss, 1860
Genus ELPHIDIUM Montfort, 1808
ELPHIDIUM DISCOIDALE ASIATICUM Polski, n. var.

Pl. 78, fig. 2a,b

Description.—The test is small, nautiloid, and lenticular in edge view. The periphery is rounded and circular in side view. The periphery is mostly entire, becoming slightly lobate in the later portion. The umbilici are flush and covered by transparent shell material revealing a small portion of the previous whorls. There are 10 to 11 chambers in the final whorl. They increase gradually in size as they are added. The chambers are slightly if at all inflated. The sutures are gently curved, almost flush with the surface, limbate, translucent, and marked with a single row of 7 to 8 septal pores on each side of the test. The surface is smooth and extremely hyaline. The wall is finely perforate. The aperture is a series of pores at the base of the last septal face. The diameter is 0.30 mm.; the thickness 0.11 mm.

Remarks.—This variety differs from *Elphidium discoidale* (d'Orbigny) (=*Polystomella discoidalis* d'Orbigny, 1839 *in* Ramon de la Sagra, Histoire physique, politique et naturelle de l'Ile de Cuba. A. Bertrand, Paris, France, p. 56, pl. 6, fig. 23–24) in being more inflated in edge view, having a more rounded and less lobate periphery, flush umbilical region and fewer septal pores.

Type figure.—Plate 78, fig. 2a, b, holotype, ×300: a, side view; b, edge view.

Locality.—Sample 9-7, latitude 37° 58′ N, longitude 121° 09′ E, depth 52 feet, sandy mud bottom. Northern Yellow Sea, Asiatic coast.

Age.—Recent.

Holotype and paratypes.—U.S.C. Nos. 4911 and 4912.

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A NEW METHOD OF FORAMINIFERAL CORRELATION

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ABSTRACT—A new means of correlation which does not require the presence of guide fossils has been developed and successfully tested. This method is new in that it utilizes the complex inter-relationships formed by overlapping occurrence patterns of individual species to develop time correlations instead of developing correlations by the matching of faunas. It augments but does not supplant present methods. It provides a means of determining sedimentary foraminiferal controls and of separating them from other environmental controls. It also provides a means of testing the reliability of guide markers.

INTRODUCTION

WEST Coast paleontologists are often faced with the necessity of correlating samples carrying undiagnostic foraminiferal faunas. In such cases much time and effort is consumed in obtaining generalized answers. The object of this work was to develop a precise means of correlating samples of this type.

The basic hypothesis upon which this method rests was first formulated in 1946. During the years 1946 to 1948 the hypothesis was formalized and a theory of application was developed.

The method was first tested in 1949; subsequently it has been applied on four occasions to correlate rocks ranging in age from middle Miocene through upper Pliocene.

The current study was initiated in June and was completed in December of 1956.

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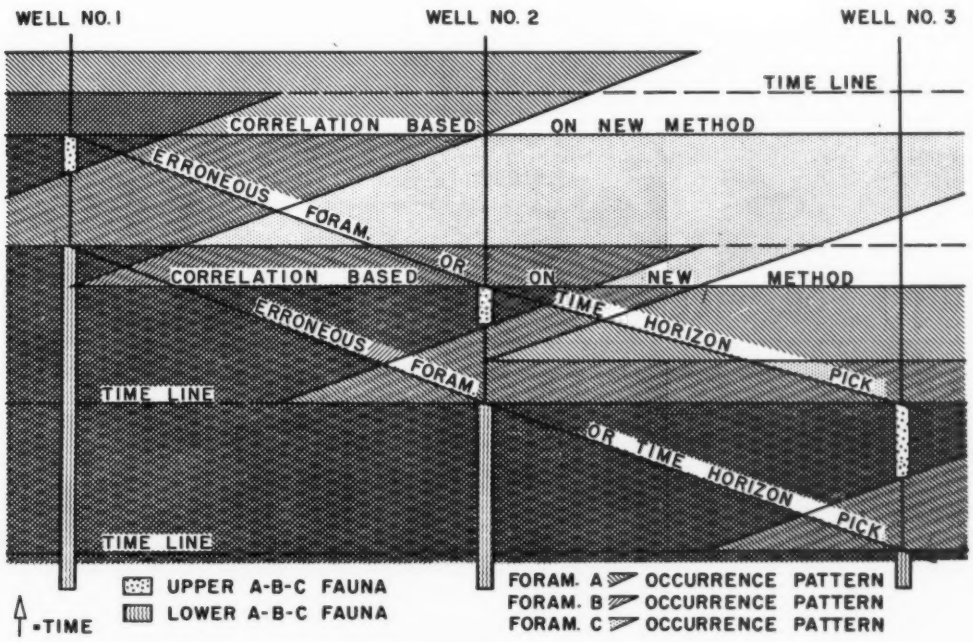
METHOD

Basic hypothesis.—The hypothesis tested by this study states that within the geologic range of any foraminifer a sufficient number of environmental factors were changing continually through time to form cycles of favorable and unfavorable environments. Each species will occur in or be excluded from an area, or portion of an area, in response to those changing factors which influence it as an individual species. Thus, small breaks in what is usually considered a continuous occurrence of a species will follow definite cyclical patterns. These patterns will vary across a given area and will differ in unrelated areas in response to the continually changing areal distribution of those factors which influence it as an individual species. Species which occur infrequently will also follow definite cyclical patterns in like manner. The cycles of occurrence and nonoccurrence of a number of species will not necessarily be contemporaneous.

The majority of horizons thus formed will be local. As such they should be approximate time lines. Geologically, significant transgression of time could occur only where a horizon covered a broad area. Wide extent of a horizon, however, would only introduce the *possibility* of time transgression.

That such cycles of alternating presence and absence can and do occur has been amply documented in the article "Varves and Foraminifera of a portion of the upper Puente formation (upper Miocene) Puente, California" by D. D. Riveroll and B. C. Jones. That these cycles are not due solely to the agencies which caused the seasonally alternating varves is attested to by the occasional occurrence of *two distinct* foraminiferal assemblages in *a single layer* of a varve couplet.

Theory of application.—If the above hypothesis is correct, plotting the pattern of



TEXT-FIG. *1*

occurrence of one foraminiferal species against another will disclose numerous correlatable horizons. Therefore, by plotting against each other the occurrence patterns of a group of species, a continuous set of correlatable time horizons will be developed (Text-fig. 1). Horizons which cover a broad area can be checked for time transgression by checking them against short but overlapping patterns of other species.

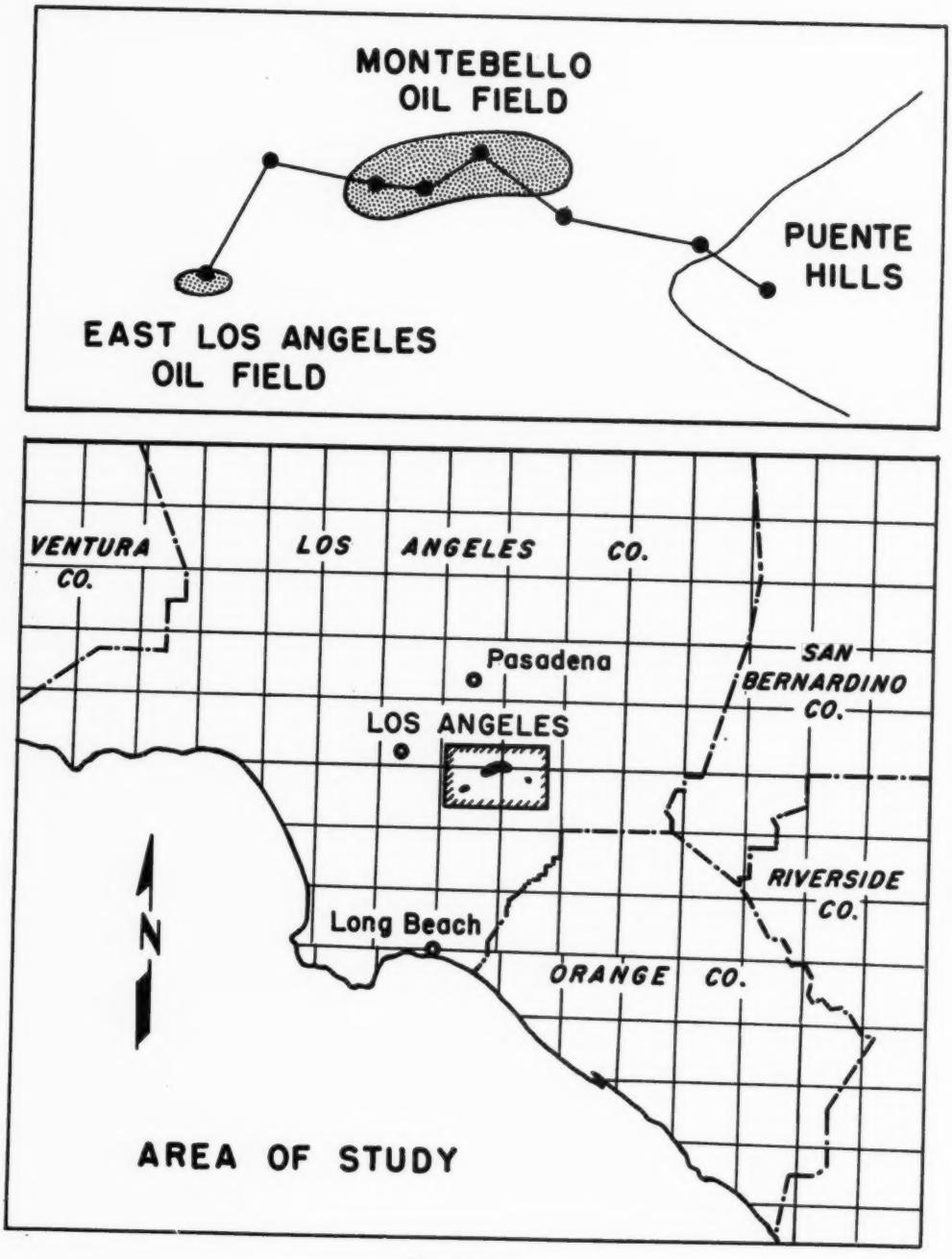
These horizons will be developed irrespective of the presence or absence of "key" faunal guides. If markers are present, however, they should be incorporated in the study. Also, in obtaining adequate control, it should not be necessary to use all foraminiferal species known to be present.

To form a system covering an entire basin, it should only be necessary to correlate the horizons of one area with those of adjoining areas at zones of overlap. In this manner time horizons could be run through differing faunas, such as from shallow to intermediate to deep water. Also, with such a system, formerly established markers could be re-evaluated and new ones discovered.

APPLICATION

Selection of material.—It should be emphasized here that for successful application of this type of work it is necessary to begin in an area in which a sufficient number of well-sampled sections are available. The Montebello oil field of the Los Angeles Basin in Southern California met these requirements (Text-fig. 2). A large number of core samples from wells in this field were available for the study. It was decided to test a 1000-foot interval in this field which bracketed the Pliocene/Miocene contact.

The first step was to select those wells which had the most nearly complete core coverage. A total of 25 wells was selected. The majority of the cored sections covered a 500-foot portion in the middle of the inter-


MONTEBELLO
OIL FIELD
PUENTE
HILLS
EAST LOS ANGELES
OIL FIELD
VENTURA
CO.
LOS ANGELES CO.
Pasadena
SAN
BERNARDINO
CO.
LOS ANGELES
RIVERSIDE
CO.
Long Beach
ORANGE CO.
N
AREA OF STUDY

TEXT-FIG. 2

val; however, a few of the wells contained cores covering the upper and lower portions of the 1000-foot interval selected. Later, upon completion of the initial study, two additional wells and two surface sections were included in order to tie in the East Los Angeles oil field to the southwest and the Puente Hills to the east.

Deep water benthonic foraminifers are native to the part of the stratigraphic column studied. Except where otherwise stated, the foraminifers discussed in this paper are of this type.

Consideration of error.—As a primary test of the hypothesis, the foraminifer which had the most continuous occurrence, *Bulimina rostrata* Brady, was selected. *Rotalia garveyensis* Natland, the next most continuously occurring species, was selected for a second test.

In selecting the above foraminifers it was considered that due to their distinctive appearance positive listings would be subject to a minimum amount of error. Negative listings, however, could be due to a number of factors. Those that could be checked and corrected involved possible errors introduced when the samples were originally picked and listed. To control these, all samples with negative listings were re-examined. Other variables could not be separated from the true absence of a foraminifer from the sediment. They constituted the known uncontrolled variables in the study. A list of these variables is shown under "Suggestions for application of method," paragraph D.

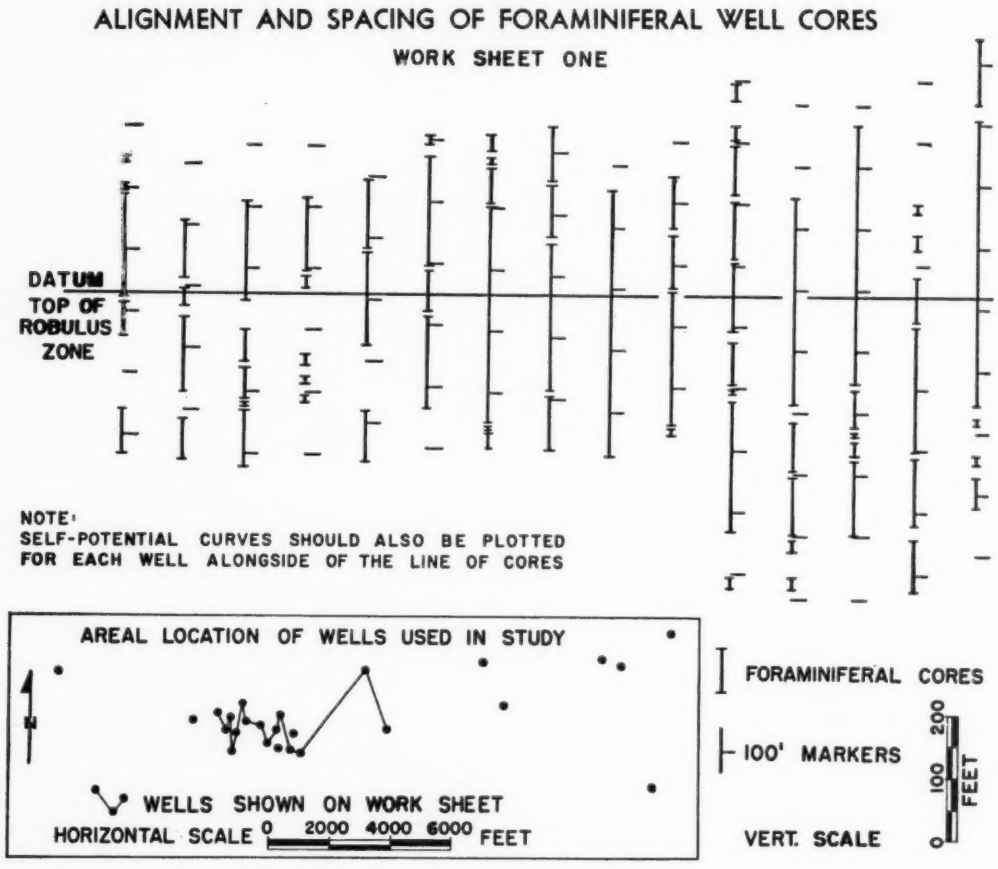
Procedure.—A master chart was first constructed by projecting all of the selected wells to an east-west line using as a datum the top of the "*Nodosaria-Eggerella* zone." For previous purposes of correlation this was considered to be the most consistent foraminiferal zone present. The foraminifer-bearing cores of each well were plotted vertically on a scale of 50 feet to the inch, with a lateral spacing of 2 inches between wells. The electric log self-potential for each well was plotted to the same scale directly to the left of the line of cores. A total of 1,134 samples was plotted. Twenty-two barren samples were cast out. Worksheet number 1 is an example of a portion of this type of chart with the electric log curves removed.

Examination of the samples disclosed that *Bulimina rostrata* Brady was found in continuous occurrence in the upper portion of the section under consideration in each well. There were 564 samples in this zone of occurrence. Ninety samples representing 16% of the 564 did not contain *Bulimina rostrata.* Experience over a period of years would indicate that a 5% error due to introduced uncontrolled variables is reasonable for a foraminiferal sampling this large. The fact that 16% of the samples examined in this study were barren of *Bulimina rostrata* indicates that approximately 11% of the absences of *Bulimina* rostrata must not be due to the effects of introduced uncontrolled variables but must be the result of a significant ecological phenomenon not heretofore analyzed.

According to the foregoing hypothesis, breaks in foraminiferal continuity should line up when plotted on the prepared chart. Those that do not would be the result of the chance influence of uncontrolled variables. According to chance hypothesis, breaks should not line up on the chart, except as the result of chance.

To test the above hypothesis, *Bulimina rostrata* was plotted on a print of the master chart. The 90 samples without *Bulimina rostrata* fell into 65 breaks, an average of 1.38 samples per break. On the initial plot all but 14 of the breaks lined up with at least 2 others in adjacent wells. Six of these fourteen, however, were in parts of the section where no lateral data were present. These 6 were eliminated from consideration. There remained 8 breaks represented by one sample each. These represented an approximate 14% mis-match of the breaks. Either the apparent correlations were due to chance or an additional uncontrolled variable or variables had been introduced in making the test. A recheck of procedure at this point failed to disclose any additional, significant, uncontrolled variables.

Rotalia garveyensis was next plotted on the same print and tested. Less data were available and the resultant test was upon a smaller group. The result, however, was not significantly different. Worksheet number 2



TEXT-FIG. 3

illustrates the patterns of *Bulimina rostrata* and *Rotalia garveyensis*.

Additional foraminiferal species, selected at random, were then plotted on separate transparent copies of the master chart. Occurrence patterns were connected using a different color for the occurrence of each species. To control possible error introduced by picking and listing, all samples with negative listings were re-examined for each of the species tested. Again a definite percentage of mis-matching occurrences and nonoccurrences was evident.

The transparencies were then laid one over the other to determine if correlatable horizons could be found. Several were discovered immediately. However, they disclosed the presence of 5 discontinuous horizons which duplicated the *key markers* of the "*Nodosaria-Eggerella* zone." No more than 3 occurred in any one well, 2 occurred in the majority, and only 1 each in a few wells. The uppermost in each well uniformly had been picked as the "*Nodosaria-Eggerella* zone." This placed the zone in the highest horizon in 2 wells, in the second highest in 17, and in the third highest in 5. Three of these had been estimated. In the remaining well a pick had not been made and the position on the worksheet was provisional.

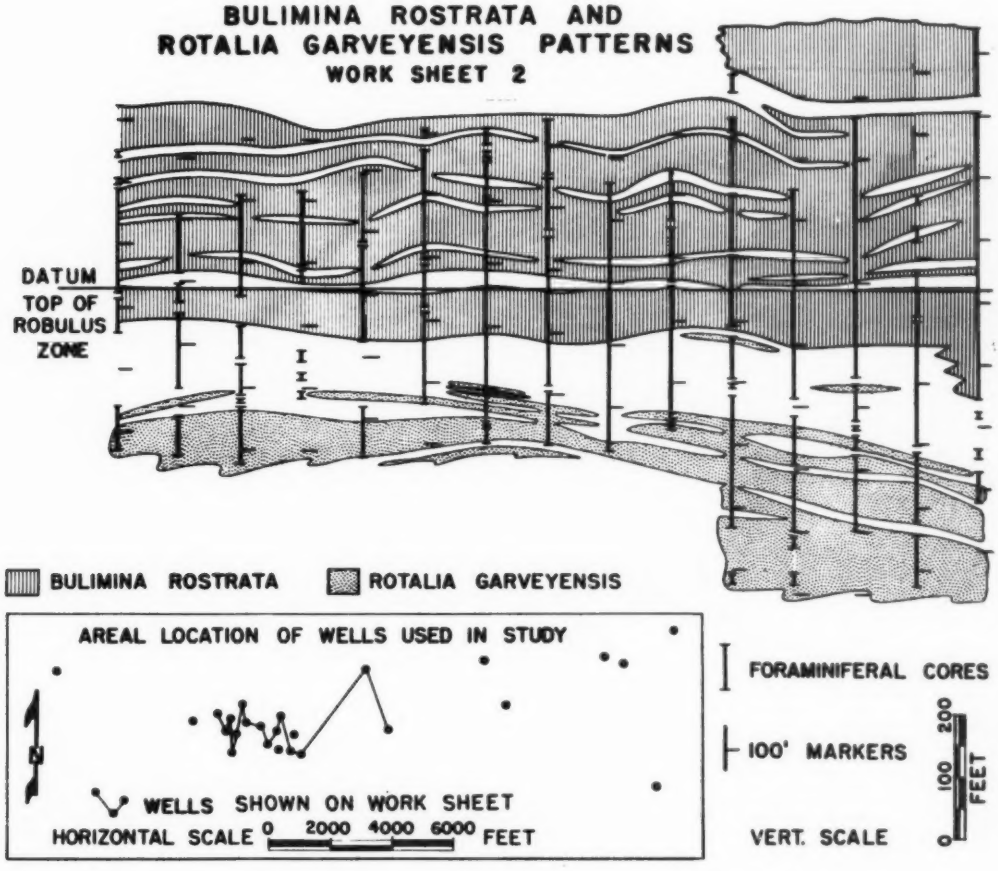
This evidence revealed the unsuspected variable of possible mis-correlation of the wells when placed on the work-sheet. All the wells were realigned on the second highest horizon. The breaks in the occurrence of *Bulimina rostrata* Brady were then recor-

related. All but 2 of the 59 usable breaks lined up on the new chart. In other words, 96% of the breaks lined up. Replotting of the other species revealed a similar high percentage of correlation. Worksheets numbers 3, 4, 5 and 6 show the sequence in the build-up of correlations by the overlaying of a group of species patterns.

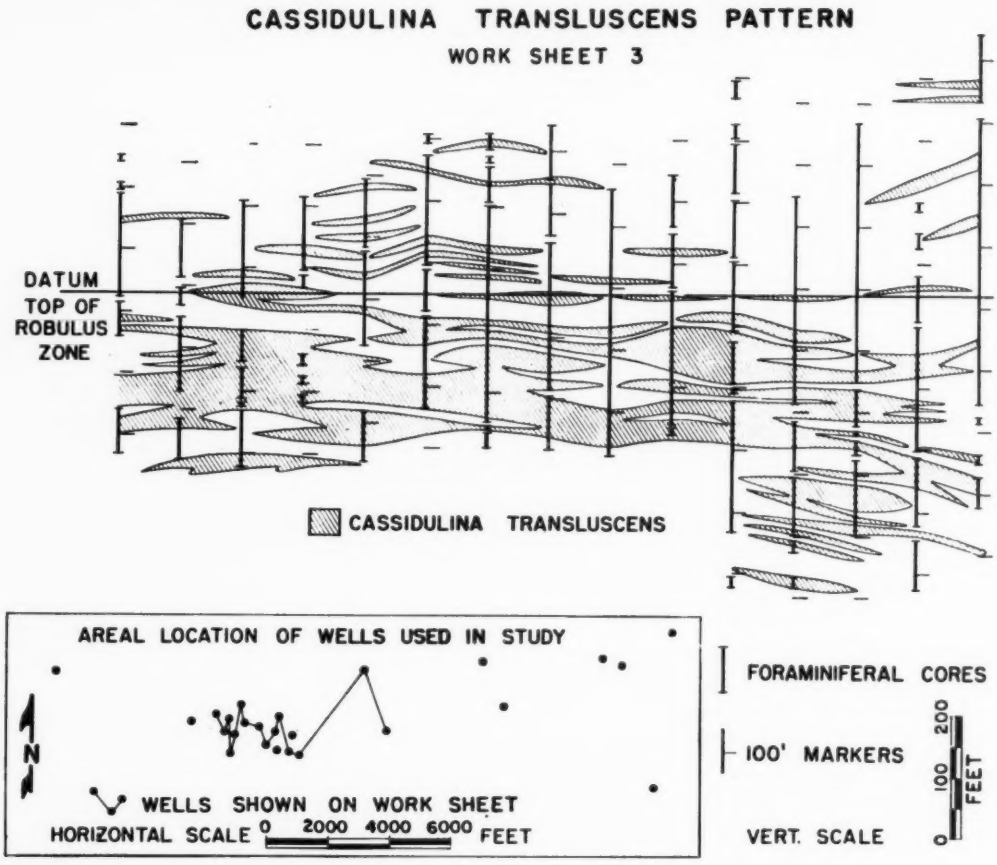
All the foraminifers which had thus far been used had occurred in the section with considerable frequency. Their use provided a test of the part of the hypothesis which states that the minute interruptions in more or less continuous occurrences of foraminiferal species were environmentally controlled and would follow definite cyclical patterns. The second part of the hypothesis, which states that species which occur infrequently will also follow definite cyclical patterns, was next tested.

For this test *Robulus americanus* Cushman var. *spinosus* Cushman was selected. In the part of the stratigraphic column under study, this species has been considered worthless for correlation due to its infrequent and apparently sporadic occurrences.

A check of the listings showed only 27 occurrences, or one in every 42 samples. These occurred in only 11 of the 25 wells. However, since this species had not previously been used, it appeared likely that it had not always been listed when found. To check this possibility, all of the remaining samples, which had not previously been checked in the other tests, were reexamined. This check increased our listings to 72, or one in every



TEXT-FIG. 4



TEXT-FIG. 5

16 samples. The presence of *Robulus americanus* var. *spinosus* in only 6% of the samples and its previously assumed sporadic nature of occurrence thus made it an ideal species for this test.

The samples were plotted on a transparency of the new worksheet. They lined up in 2 occurrences covering a zone which averaged 68 feet thick. The upper occurrence averaged 26 feet, the lower occurrence averaged 22 feet and the break between them averaged 20 feet. The thickest interval for the zone in any one well was 100 feet, the thinnest was 42 feet. Thirteen of the 25 wells were found to have cores covering the entire zone. Six wells had cores covering a part of the zone, and 6 wells had not been cored in the zone. Worksheet number 7 shows the pattern of *Robulus americanus* var. *spinosus* occurrences.

This represented a 100% correlation of the samples in the test, as all 72 of these samples lined up. It confirmed the new correlation of the wells, which was based upon the set of correlatable horizons developed by matching the patterns of the more numerous species against each other. It seems unreasonable to assume that the high frequency of correlation throughout the section under study is due to chance alone. Thus the hypothesis that the many minute interruptions in the occurrences of foraminiferal species throughout their known ranges were environmentally controlled and that

they would follow definite cyclical patterns is considered to have been adequately tested and found to be valid.

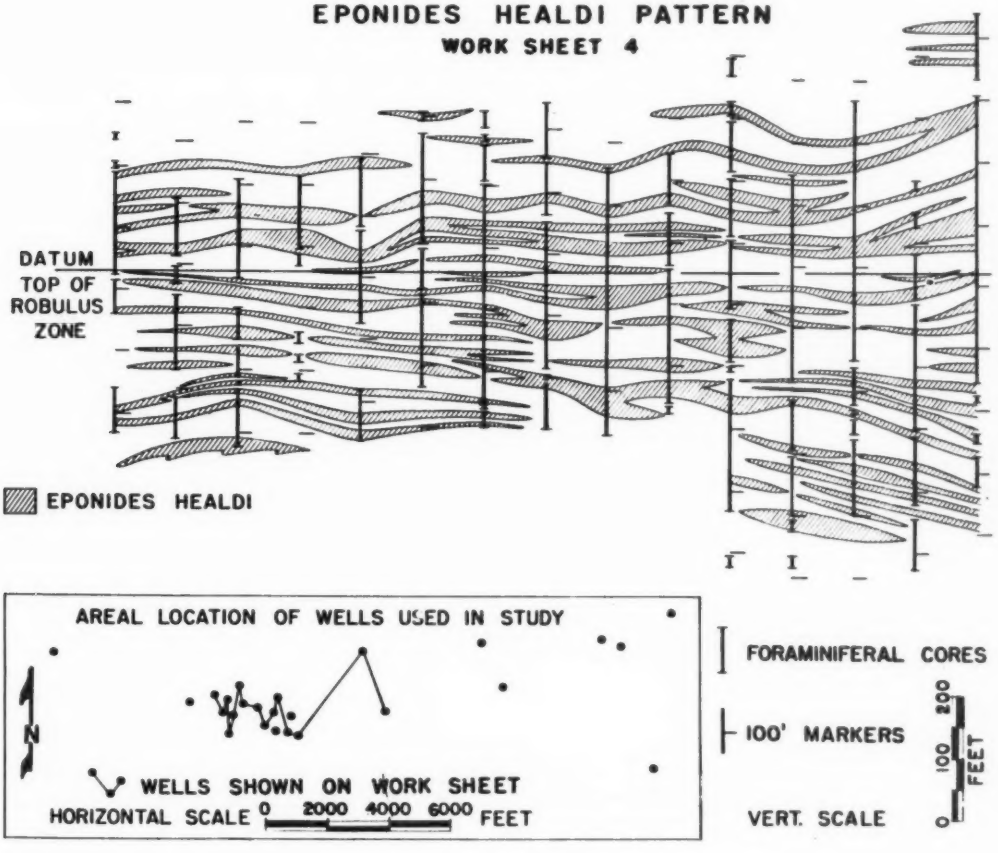
ANALYSIS OF ENVIRONMENTAL CONTROLS

The discovery of the very restricted one species zone formed by the occurrences of *Robulus americanus* var. *spinosus* Cushman provided a means of evaluating one of the environmental factors controlling the foraminiferal patterns of occurrence in the area. In "Foraminiferal shell form, a key to sedimentary environment" (Hendrix, 1958), the author provided a basis for evaluating the sedimentary environment by the shell form of the foraminifers. The occurrences of *Robulus americanus* var. *spinosus* indicated that the sediment upon which it lived had been formed into a firm stratum by highly energetic depositional forces. The zone of *Robulus americanus* var. *spinosus* occurrences will hereinafter be referred to as the *Robulus* zone. The term "zone" in this instance refers to the extremely thin local interval of occurrence of the species within and adjacent to the area of this study.

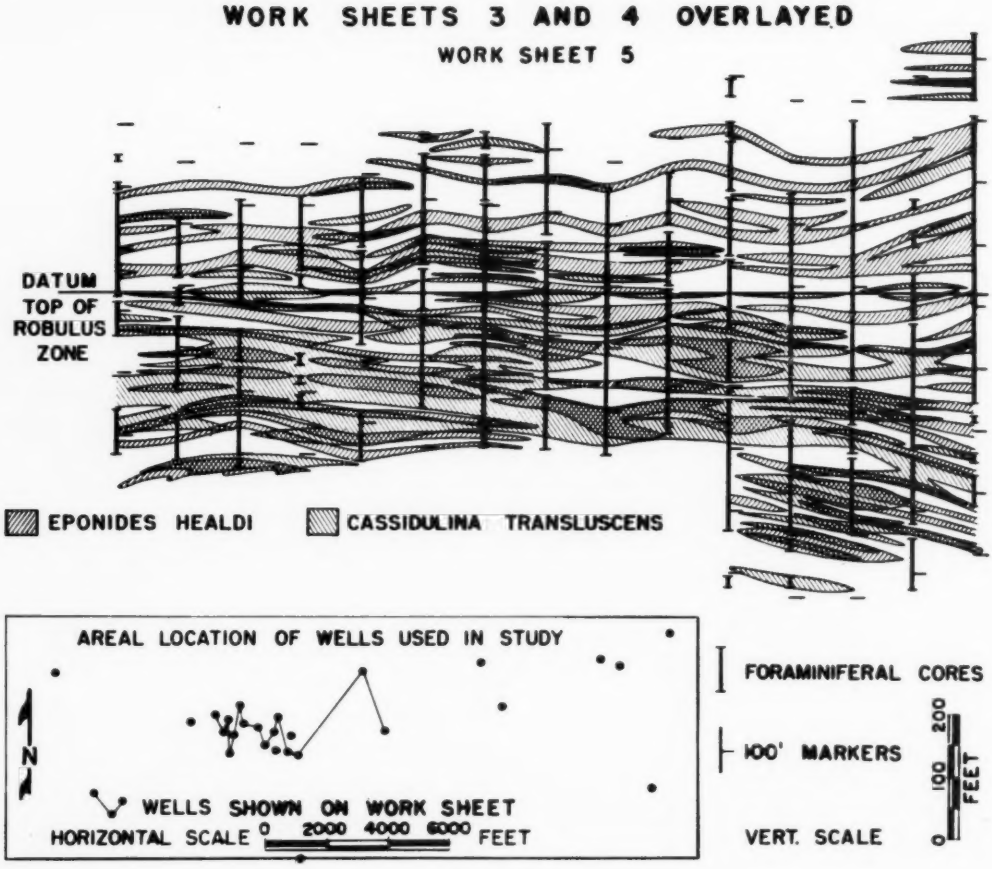
A check of the foraminifers occurring in the study section disclosed the following additional species which indicated the presence of high energy depositional forces:

Nodosaria cf. *N. verneuili* (d'Orbigny)
Uvigerina hispida Schwager
Liebusella pliocenica (Natland)

These species were plotted on separate transparencies. Their patterns indicated a zone of vigorous sedimentation which ap-



TEXT-FIG. 6



TEXT-FIG. 7

peared to have the *Robulus* zone approximately in the center. See worksheets numbers 8 and 9.

To check more precisely this sedimentary zone, two arbitrary time lines were drawn. These were drawn along what appeared to be the horizons of greatest change from vigorous to less vigorous conditions. The zone thus defined will hereinafter be referred to as the High Energy zone. It has an average thickness of 215 feet. A count of these foraminifers revealed them to be present in the percentage of the samples shown in the following table.

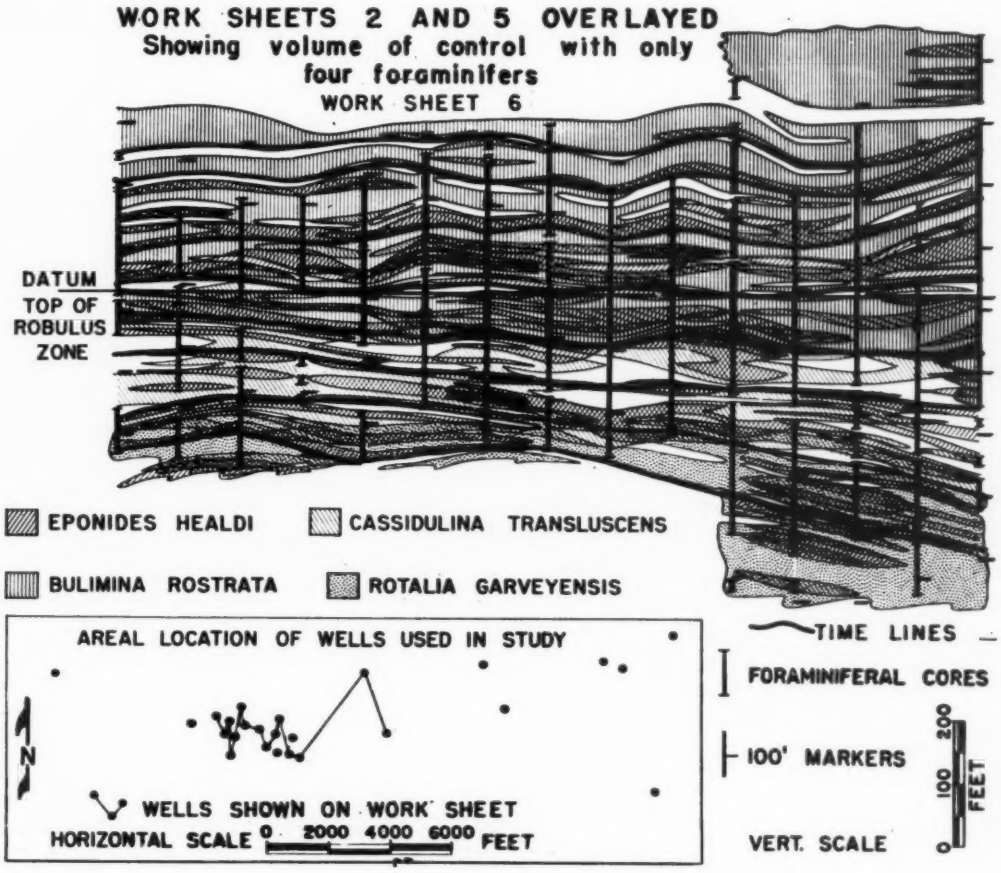
	Above Zone	High Energy Zone	Below Zone
Average thickness in feet	154	215	431
Total number of samples	244	483	407
Nodosaria verneuili	9%	26%	6%
Uvigerina hispida	21%	26%	0%
Liebusella pliocenica	6%	31%	12%

From the above it can be seen that the highest frequency of occurrence of *Nodosaria verneuili* and *Liebusella pliocenica* fall clearly within the zone. However, the occurrences of *Uvigerina hispida* are almost as frequent above as within the zone. Inspection of worksheet number 9 will show that the lowest occurrence of *Uvigerina hispida* is just above the *Robulus* zone. When the

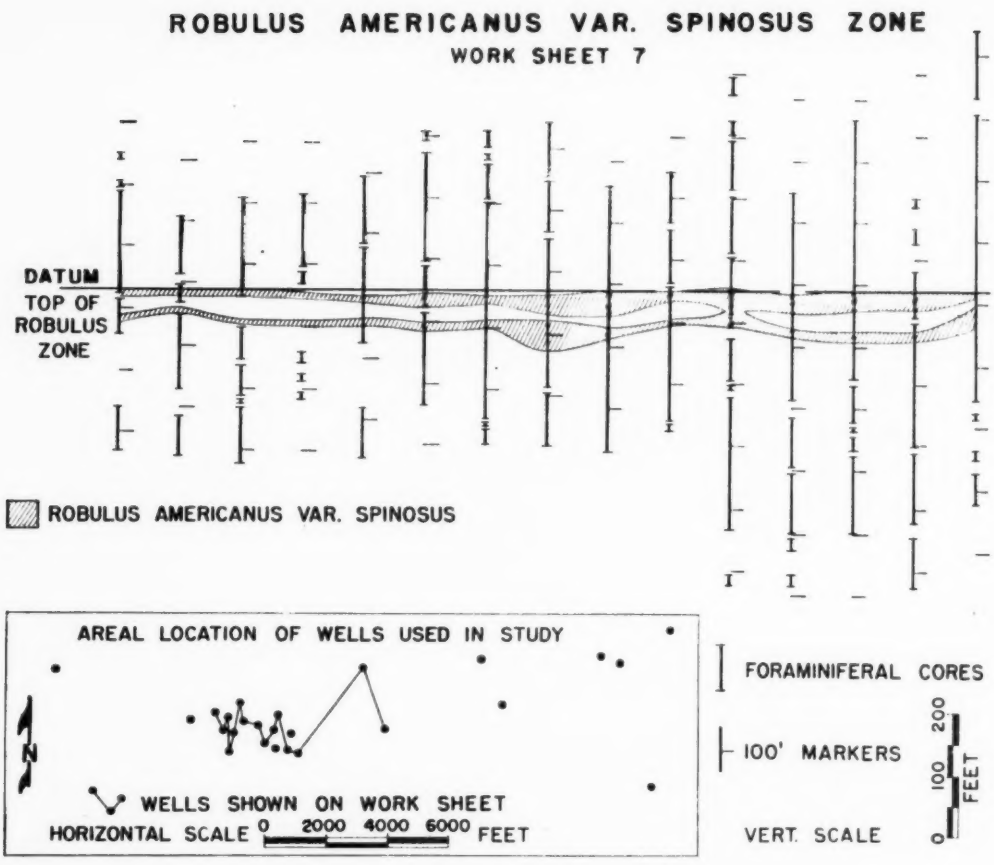
percentage of *Uvigerina hispida* was computed for that portion of the High Energy zone above the *Robulus* zone, it was found to be 54%. If the upper limit of the zone had been set 40 feet higher, the frequency of occurrence within the zone would have been approximately twice as great as it would have been above. The occurrences of *Uvigerina hispida* appeared to indicate that the center of the High Energy zone was approximately 70 feet higher than did the occurrences of the other three foraminifers.

In order to clarify this picture another approach was tried. From the author's work on the previously cited paper, it was found that redistributed foraminifers occurred most frequently in sediments deposited in the high energy foraminiferal environments. There should then be a greater frequency of occurrence of redistributed foraminifers in the High Energy zone, if it had been properly defined.

To check the zone, redistributed shallow water foraminifers were selected. These were plotted on worksheets and the frequency of their occurrences computed. The worksheets revealed that no one species and no one genus would form a correlatable group of occurrences. However, when all shallow water forms were plotted together as a group on the same worksheet, they formed many short discontinuous occurrence groups. See worksheet number 10. The percentage of occurrences for the redistributed foraminifers as well as the average of the native deep water foraminifers is tabulated



TEXT-FIG. 8



TEXT-FIG. 9

in the following table:

	Above Zone	High Energy Zone	Below Zone
Average thickness in feet	154	215	431
Total number of samples	244	483	407
Redistributed Forms	8%	18%	8%
Native Forms	12%	28%	6%

As can be seen from the above table, the highest frequency of redistributed shallow water foraminifer occurrences falls within the High Energy zone, as indicated by the native deep water forms *Nodosaria verneuili*, *Robulus americanus* var. *spinosus*, and *Liebusella pliocenica*. See worksheet number 11.

The occurrences of shallow water foraminifers were more than twice as numerous within the zone than above or below it. This would indicate that the pattern of occurrences of *Uvigerina hispida* differed from that of the other three deep water species as a result of variables that were not of sedimentary origin.

Within the *Robulus* zone there is a 20-foot break between its upper and lower occurrences. The occurrences of 10 other species present in the zone were checked against the *Robulus* pattern of occurrence. It was found that one species, *Bulimina rostrata*, occurred continuously throughout the zone, 4 species occurred discontinuously throughout the

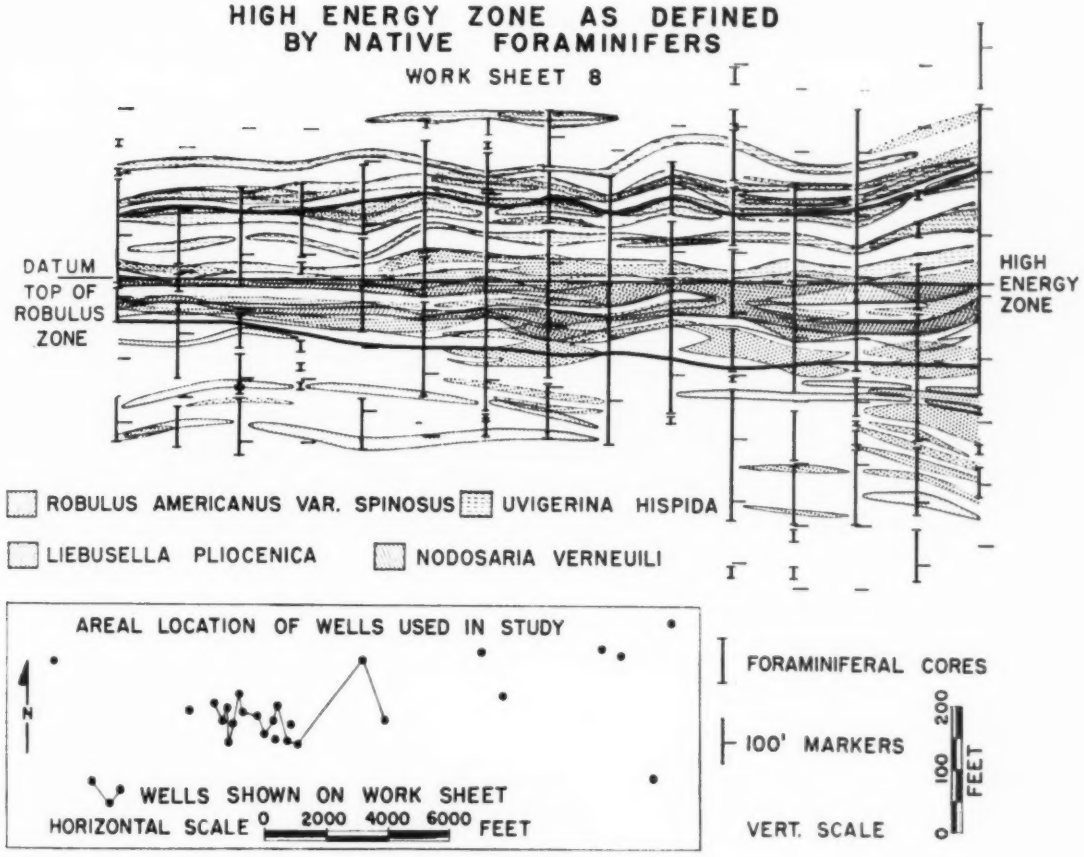
zone and 5 species occurred only with the lower *Robulus* occurrence. Each of the 11 species, counting *Robulus americanus* var. *spinosus*, had a distinct pattern of its own through the zone. These distinctive patterns cannot be due solely to sedimentary variables. It will be necessary to evaluate other environmental controls, physical, chemical and biological, to determine the other causes for the diversity of occurrence patterns.

ADDITIONAL DATA

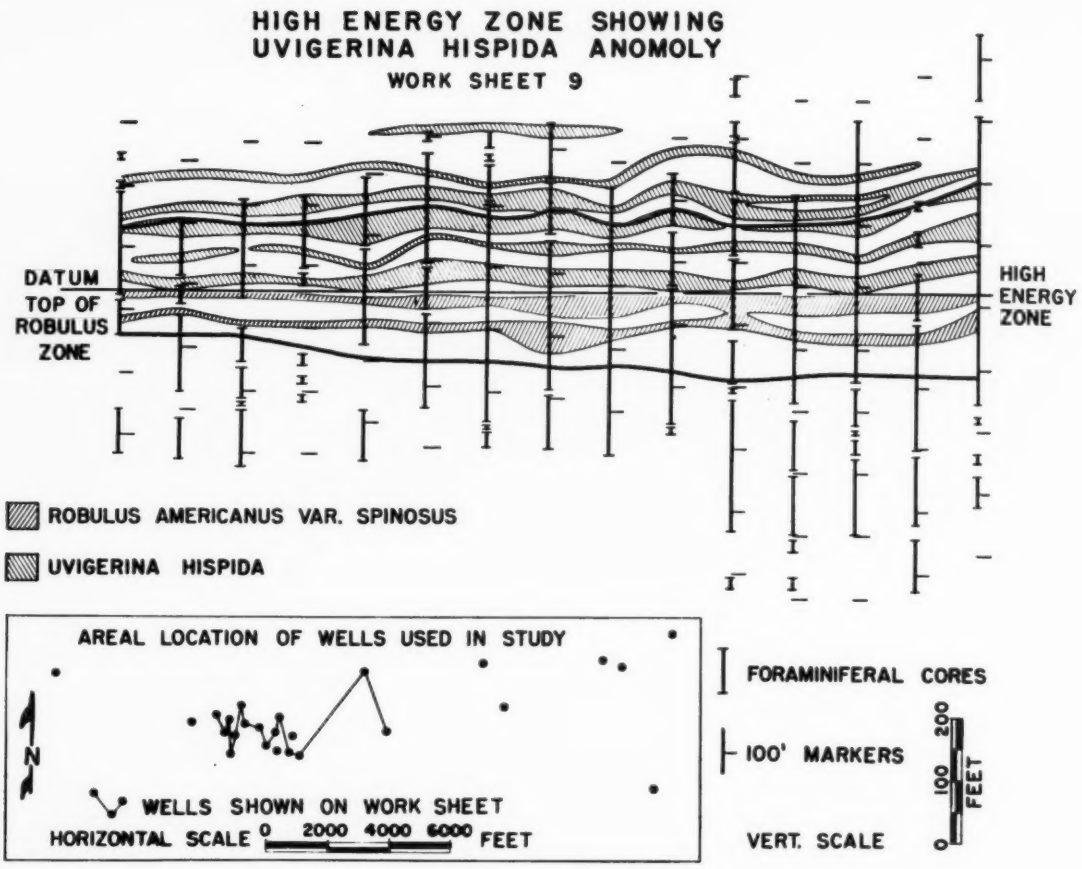
To bring out a large number of correlatable horizons, approximately 8,000 entries were made using 25 separate species or groups of species. A list of these foraminifers appears at the end of the report.

By selecting 12 of the species, such complete control was obtained that a point could be picked at random in any well and its counterpart located in any of the other wells. Adequate control was obtained by using only 6 of the foraminifers. This is 1/4 of those tested, which is in turn approximately 1/4 of the species commonly found in the section.

The use of a well within the area studied, which had only 2 cores, indicates the feasibility of using ditch samples when only a few cores are available. Unexpectedly good correlation was obtained with these cuttings. It also demonstrates the practicality of making accurate correlations by the method described when only a few cores are available. This well initially was correlated



TEXT-FIG. *10*



TEXT-FIG. *11*

by using only 2 cores. These 20-foot conventional cores which contain no key horizon markers were cut approximately 800 feet apart. Four foraminifers were selected, *Pullenia bulloides* and *Uvigerina hispida*, in the upper core, and *Nodosaria* cf. *verneuili* and *Rotalia garveyensis*, in the lower core. The pair of horizons formed by these foraminifers was plotted on the chart and correlation was readily demonstrated. The ditch samples were then plotted in the gap and verified the correlation.

An important discovery was that of the extreme local irregularity of the top occurrences of the guide fossil *Rotalia garveyensis* Natland. The approximate upward limit of this fossil has generally been used in conjunction with associated foraminifers to determine the Pliocene/Miocene boundary (Wissler, 1943; Wissler & Crawford, 1948; Natland & Rothwell, 1954; Natland, 1957). While the gross top of *R. garveyensis* is believed to be reliable, this local irregularity is quite well illustrated in worksheet number 2 and in the fence diagram. This illustrates the danger of picking first occurrences of this foraminifer for precise local correlations.

Another important discovery was that of the local differences in the base of the continuous occurrence of *Bulimina rostrata* Brady in the Montebello oil field. This base is quite uniform in both the eastern and western portions of the field; but it is 100 feet lower in the eastern than in the western. The break between the two levels is sharp and shows no apparent relationship to the patterns of the other foraminifers. This may be seen in worksheets numbers 2 and 5. It

also illustrates the danger of using the base of the continuous occurrence of this fossil for precise local correlations.

CORRELATIONS BETWEEN AREAS

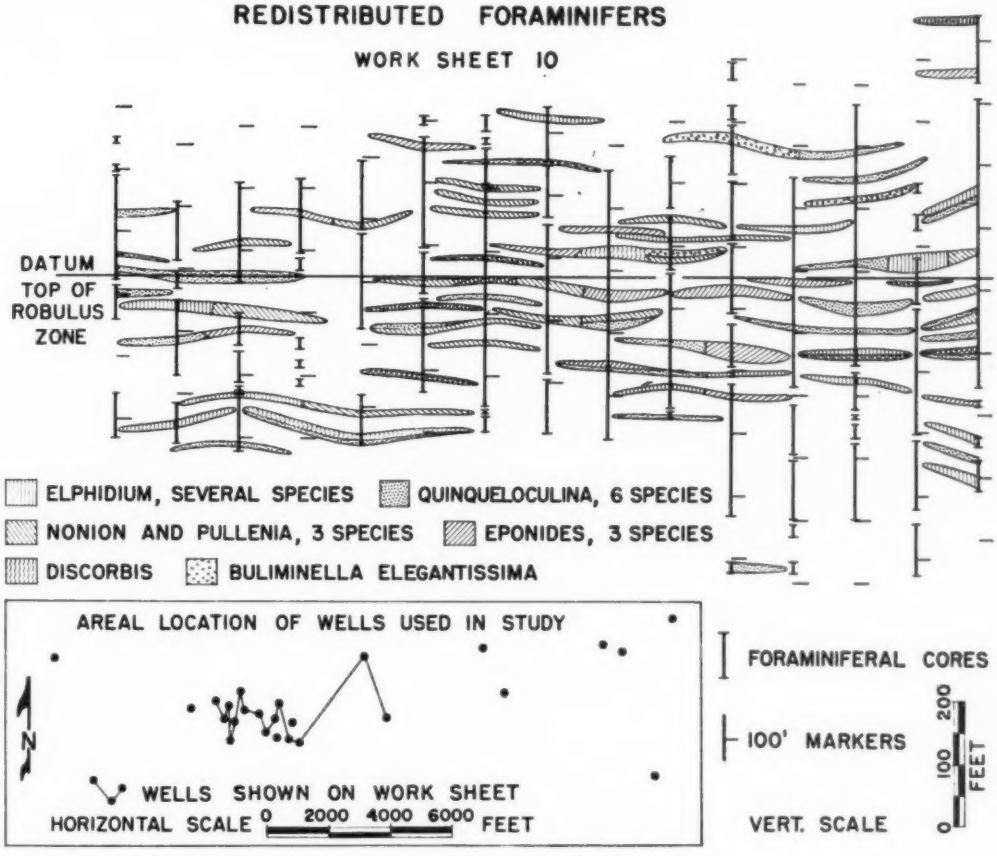
The fence diagram illustrates the time correlation of the Montebello oil field with the East Los Angeles oil field to the southwest and with the western portion of the Puente hills on the east. Since the *Robulus* zone occurs across this entire area, it was used as the datum for the diagram.

To correlate the Montebello oil field with the East Los Angeles oil field, it was necessary to use an intermediate well and trace a sufficient number of occurrence patterns into it from each oil field to form a recognizable group of overlaps. By this means it was determined that the *Robulus* zone represented the same time horizon in both oil fields.

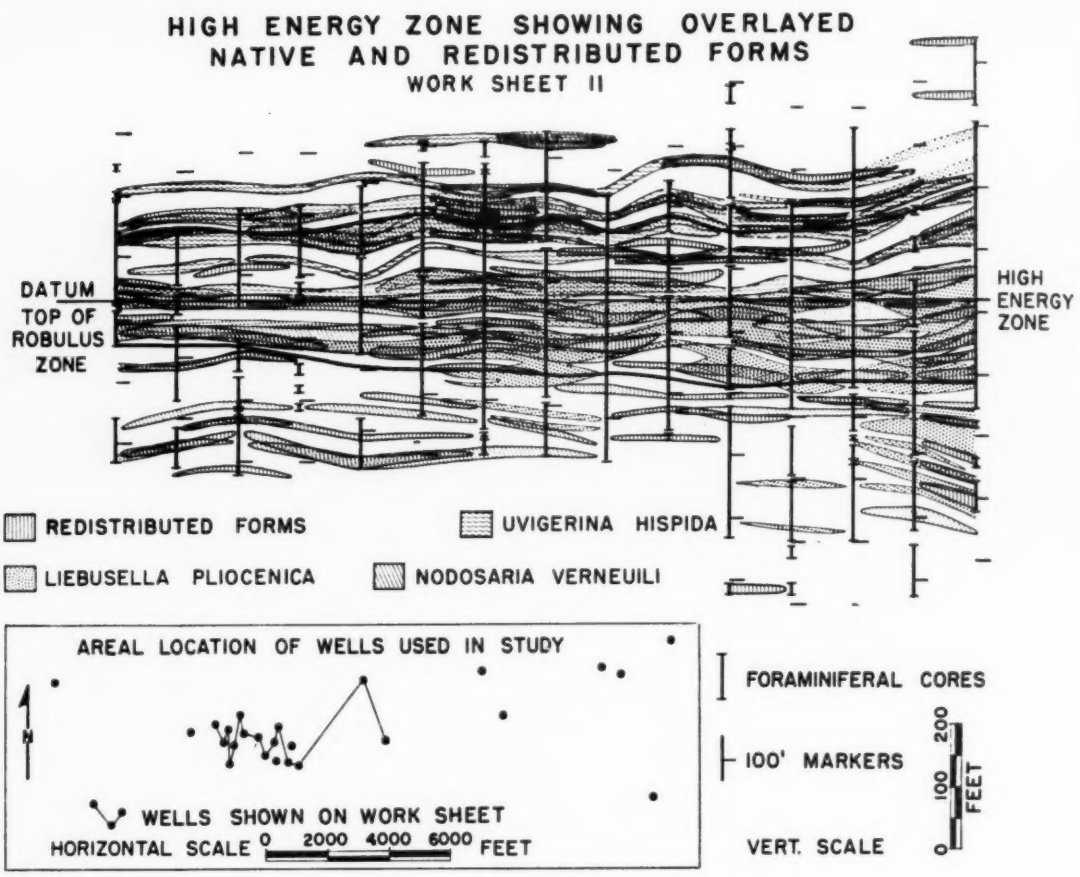
It can be seen from the fence diagram that the lower portion of the *Robulus* zone does not quite reach the East Los Angeles oil field. The upper portion of the zone only reaches the northern end of the field in the well represented on the diagram. Beyond this point equivalent time is represented by a noticeably less energetic sedimentary environment.

To check this correlation, independent electric log correlations were made without knowledge of the foraminiferal data. Comparison of the two correlations showed that the *Robulus* zone in both fields matched exactly with the electric log correlations.

To correlate between the Montebello oil field and the Puente hills, it was necessary to



TEXT-FIG. *12*



TEXT-FIG. *13*

carry the time horizons through two intermediate wells and one surface section, to the surface section represented in the diagram. The two intermediate wells lie in the pass known as the Whittier Narrows which lies between the Merced Hills on the west, in which the Montebello oil field is located, and the Puente Hills on the east. These two wells through which the correlations were carried indicated sedimentational energies were even higher than in the Montebello field. The fifth section from the left on the fence diagram shows a wide break where the *Bulimina rostrata* occurrences are split by a great mass of sand which is presumed to have been deposited by a sequence of turbidity currents.

As the time lines are traced from the easterly well into the westernmost surface section in the Puente Hills, they pass south of the limits of the High Energy zone. Neither the *Robulus* nor any of the other high energy indicators are represented. Instead, a distinctly diatomaceous zone about one hundred feet thick appears in the section approximately two hundred feet below where the equivalent of the *Robulus* zone occurs.

The surface section represented on the diagram lies to the northeast of the abovementioned surface section. It is far enough north to catch both the upper and lower occurrences of the *Robulus* within its zone. However, none of the other high energy indicators found in the Montebello oil field appear to have reached beyond the Whittier

Narrows to this location. From this evidence it may be assumed that the High Energy zone dies out to the east as a distinct zone.

The wedge-edge of the diatomaceous zone found in the first-mentioned surface section reached both the nearby well to the northwest and the nearby surface section to the northeast. Occurrence patterns of three diatoms and five radiolarian species can be traced through these three locations.

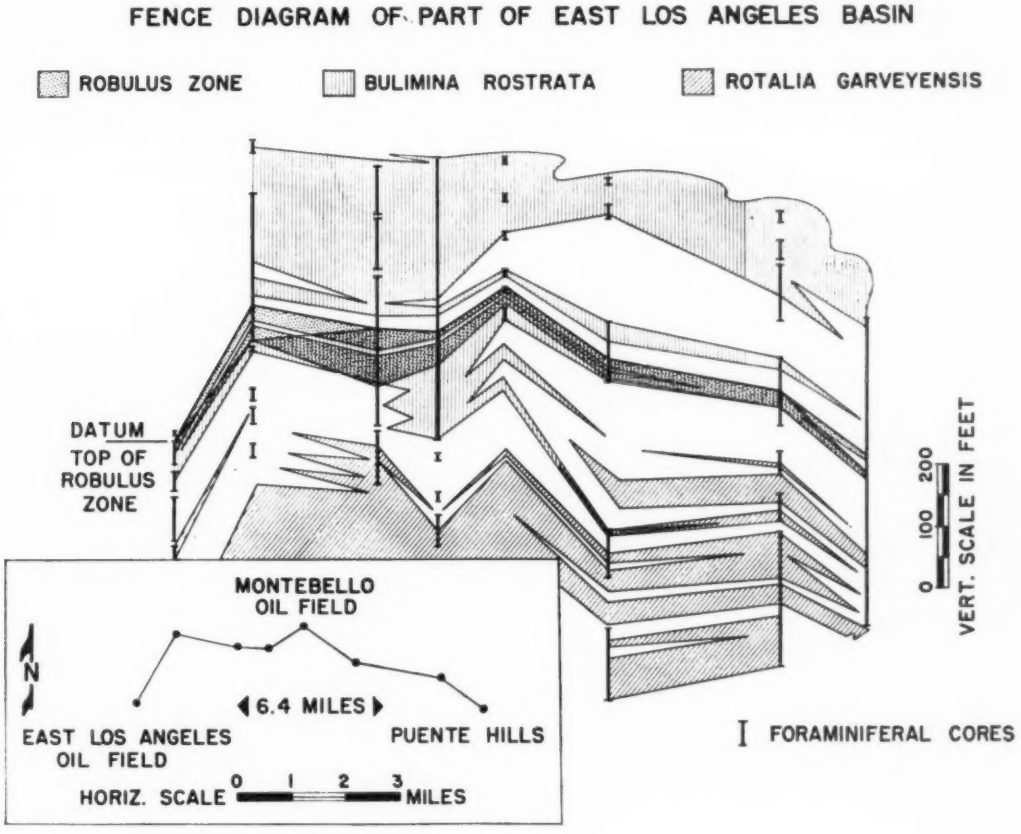
The time lines from the Montebello oil field to the Puente hills were followed by tracing different occurrence patterns from overlap to overlap across the area correlated. In one case the foraminiferal correlations verified previous electric log correlations; and in the other they were made the basis for changing tentative electric log correlations to others which were considered to be more reasonable by the geologist concerned. The *Robulus* zone was found to occupy the same time horizon in its Puente hills occurrence as it did in the Montebello oil field.

Although correlation in a strict time sense has only been carried across differing deep-water environments, the author is currently working with definite promise of success on a project to carry time lines from deep- to shallow-water environments.

ILLUSTRATIONS

Illustrations of a portion of the worksheet have been prepared at a reduced scale and without the electric log curves. The worksheet has been redrawn with the datum placed at the top of the *Robulus* zone.

These illustrations have been arranged to show two sets of sequences. The first set (Text-figs. 3–9) illustrates the patterns of four species as individually plotted. These



TEXT-FIG. 14

have then been overlaid and a few correlation lines drawn to illustrate the use of the method.

The second set (Text-figs. 10–13) illustrates the change in sedimentational control across the High Energy zone as reflected in the distribution of occurrence patterns of the native and redistributed foraminifers.

The fence diagram (Text-fig. 14) was constructed to illustrate three dimensional relationships in the vicinity of the Pliocene/Miocene contact. On it are plotted the patterns of *Robulus americanus* var. *spinosus*, *Rotalia garveyensis*, and *Bulimina rostrata*. The datum line is the top of the *Robulus* zone. The diagram contains a well in the East Los Angeles oil field as the southwestern terminus. It passes eastward through the Montebello oil field to a well at the western end of the Puente Hills, thence to the eastern terminus, which is a surface section in the Puente Hills. This illustrates the changing patterns of occurrence of the two species, *R. garveyensis* and *B. rostrata*, in response to the changes in sedimentary and other controls through this section.

CONCLUSION

It has been shown that small breaks in otherwise continuous occurrences of individual foraminiferal species form consistent patterns and that these may be used to determine time correlations. It has also been shown that intermittently occurring species form consistent patterns if they are native to the sedimentary environment. They may also be used for correlation. It was found that redistributed species *do not* form consistent patterns. This provides an additional means of determining whether a given species is native to the enclosing sediment or whether it has been redistributed.

The occurrence of thick-walled and heavily ornamented forms, in conjunction with the increase in frequency of occurrence of redistributed forms, indicates that sedimentational energy is one of the important variables controlling the distribution of foraminiferal occurrence patterns. Changes in sedimentary energy levels in both time and space can be traced by the use of these criteria.

In addition to sedimentational variables, others of physical and chemical nature unquestionably control foraminiferal occurrences. However, it would hardly seem possible to account for all of the innumerable variations and intricate interrelationships revealed by the overlapping patterns by known physical and chemical variables. On the other hand, the complex of biological coactions known to exist in present day environments appears to be a logical indication of probable biological control for many of these variations. The dominantly sedimentational controls now recognized can be separated from those which are as yet not recognized, as illustrated by the example of *Uvigerina hispida*.

The ability to correlate by this method on a continuous basis within well or surface sections makes it possible accurately to tie in isolated, undiagnostic samples from poorly cored wells within the area. It also makes possible the accurate evaluation of guide fossils in correlation, as demonstrated by the charting of *Rotalia garveyensis*.

Ditch samples have been tested by this method in one well. More precise correlations were obtained in this test than had been possible previously, thus indicating the probability of improved correlations derived largely from well cuttings.

By the correlation of the test area with two adjacent areas, it has been shown that areas controlled by the method can be accurately inter-related.

The author believes this system should be applicable to any portion of the geologic column when adequate control is available.

SUGGESTIONS FOR APPLICATION OF METHOD

A. In preparing a worksheet, the vertical scale should be made as large as possible; and sections should be placed as close together as possible. Electric log self-potential curves should be incorporated with the well sections and lithologic graphs with the surface sections. All foraminiferal surface and well samples should be plotted on the sheet.

B. If a recheck and relisting of all samples is not contemplated, only those species which have been considered sufficiently important to have been listed every time they have been observed should be considered for plotting. Of this group only those which have characteristics distinctive enough to eliminate the possibility of mistaken iden-

tity should be used. Never group two or more species together unless they are known to have been redistributed.

C. After plotting several species on separate work-sheets, connect the plots using the log curves as a guide. Next lay one sheet over another and realign connections where sharp divergences in patterns occur. This includes divergences with the well log and surface sample lithology curves. Repeat this latter step with all worksheets until all discrepancies have been resolved.

D. If discrepancies cannot be resolved, check for errors in the following:

1. Correlation of sections on master worksheet.
2. Plotting of sections and curves on master worksheet.
3. Plotting of species on worksheet.
4. Listing of species.
5. Picking of samples.
6. Selection of sample material for washing.
7. Sampling of well cores or surface sections.
8. Measurement of well or surface sections.
9. Labelling of samples at any of the above steps.

E. If discrepancies are limited to a few species while the remainder form consistent patterns, these few are probably redistributed.

LIST OF FORAMINIFERS USED IN TEST

Native forms.—

Bolivina sinuata Galloway & Wissler*
Bulimina rostrata Brady, of authors*
Bulimina subacuminata Cushman & Stewart
Cassidulina transluscens Cushman & Hughes*
Cibicides mckannai Galloway & Wissler, variety*
Eponides healdi R. E. & K. C. Stewart*
Eponides tenera (Brady)
Globigerina, at least 3 spp., incl. *G. bulloides* (d'Orbigny) and *G. apertura* Cushman*
Globorotalia menardii (d'Orbigny), of authors*
Gyroidina soldanii (d'Orbigny)
Liebusella pliocenica Natland*
Nodosaria insecta Schwager, of authors*
Nodosaria cf. *N. verneuili* (d'Orbigny)*
Pullenia bulloides (d'Orbigny)*
Robulus americanus Cushman var. *spinosus* (Cushman)*
Rotalia garveyensis Natland*
Textularia sp.*
Marginulinopsis capistranoensis White*
Uvigerina cf. *U. beccarii* Fornasini*
Uvigerina hispida Schwager, equals *Hopkinsina nodifera* Natland*

Redistributed forms.—*

Buliminella elegantissima d'Orbigny
Discorbis campanulata (Galloway & Wissler) var.
Elphidium granulosum (Galloway & Wissler)
Elphidium, 3 spp.
Eponides frigidus (Cushman) var. *calidus* Cushman & Cole
Eponides cf. *E. peruvianus* (d'Orbigny)
Eponides sp.
Nonion scapha (Fichtel & Moll), of authors
Nonion cf. *N. scapha* (Fichtel & Moll), of authors
Pullenia salisburyi R. E. & K. C. Stewart var.
Quinqueloculina seminula Linné
Quinqueloculina akneriana d'Orbigny, of authors
Quinqueloculina crassa d'Orbigny
Quinqueloculina, 3 spp.

* Denotes forms which have been plotted on transparencies of the master chart.

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 606–630, PL. 79, 10 TEXT-FIGS., JULY 1959

SEASONAL VARIATIONS IN INTERTIDAL FORAMINIFERA OF SANTA MONICA BAY, CALIFORNIA

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University of Southern California, Los Angeles

ABSTRACT—Seven sampling localities were established within the intertidal zone of Santa Monica Bay, California. Weekly collections of sand samples were made during the period from September 22, 1956 to April 18, 1957 and a total of thirty samples was collected at each station. The sand was analyzed for foraminiferal content, median grain size, and degree of sorting in order to determine seasonal variations in both the sand and the Foraminifera. A total of 53 genera and 129 species of Foraminifera was found. Only 17 of these species were found living in this intertidal environment. One new species, *Scutuloris redondoensis*, is described. There is evidence that planktonic Foraminifera are carried into shore at times of storm activity. Also, a reworking of fossil fauna both from offshore sediments of Miocene and Pliocene age and from the Pleistocene strata cropping out in the marine cliffs bordering the beaches is indicated. A correlation is established between the abundance of Foraminifera and the median grain size of the sand.

The temperature of the sea water has a direct bearing on seasonal variations in living foraminiferal assemblages, and affects the total number of specimens found in the beach sands. Wave activity and longshore current, on the other hand, cause a seasonal variation in the number of reworked and displaced Foraminifera, since these are the prime methods by which the tests are brought to the beach.

During the course of this survey, data as to the pH, salinity, heavy mineral concentration and calcium carbonate percentage were collected. These factors varied very slightly and, therefore, did not noticeably affect the seasonal trends of the foraminiferal assemblages.

INTRODUCTION

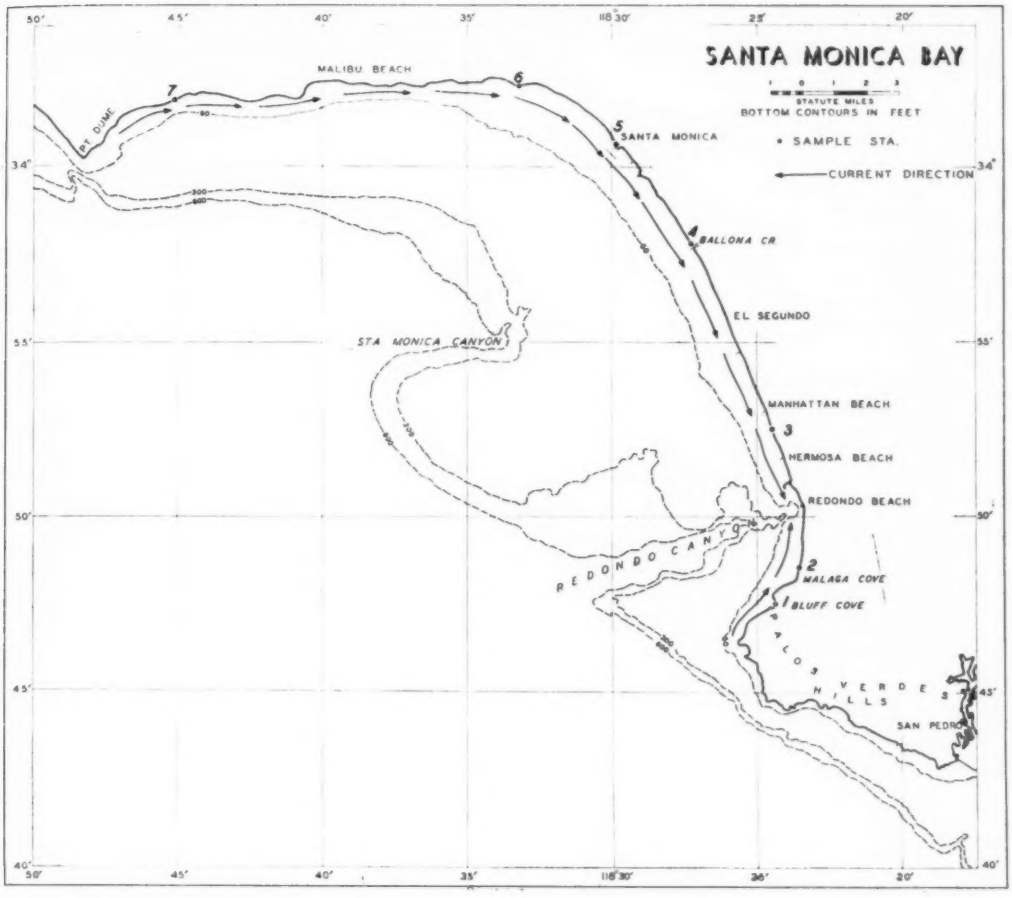
THE primary purpose of this study was to determine seasonal variations in intertidal assemblages of both living and dead Foraminifera and to account for the changes that occurred. The importance of understanding the relationships of reworked, displaced and living Foraminifera is vital to a comprehension of the significance of these factors for ecologic study, as well as to their value in stratigraphic interpretation of other sediments. For this reason samples were collected at intervals of one week for a period of seven months from seven stations along the coast of Santa Monica Bay (Text-figure 1).

In any study of Foraminifera the sediment in which these animals occur plays an important role in the analysis that may be made. It was, therefore, necessary that the sand samples be studied and a correlation established wherever possible of the relationship between the sediment and the foraminiferal assemblage.

LOCATION

Santa Monica Bay is a roughly crescent-

TEXT-FIG. 1—Map showing location of Santa Monica Bay.



TEXT-FIG. *2*—Index map of sample localities.

shaped portion of the southern California coast extending from Point Dume on the north and west to the Palos Verdes Hills on the south, a distance of approximately 36 miles (Text-figure 2). The shore from Point Dume to Santa Monica trends a little north of east and may be considered as being parallel to the trend of the Santa Monica Mountains which border it on the north. This stretch of coast is characterized by a large number of rocky points and intervening sandy beaches. The points consist of rock more resistant to marine erosion than that which occupies the coves. Several short, steep, intermittent streams occur along this part of the bay, and during periods of heavy rainfall they pour large quantities of water and rock debris from the mountains directly into the sea. These streams are the main sources of sediment to these beaches.

From Santa Monica to Palos Verdes Hills the coast runs nearly southeast by south, having only a slight convexity toward the northeast. This part of the bay marks the western boundary of what is considered the Los Angeles Plain, a low-lying area with but two streams which empty into the bay (Ballona Creek and Centinela Creek). Both of these creeks have small drainage areas and low gradients, and both empty into Ballona Lagoon, depositing most of their sediment before they reach the bay. Neither is considered an important source of intertidal sediment.

Near the City of Santa Monica the beach is backed for several miles by a high marine

cliff cut in unconsolidated terrace deposits. Sand dunes line the coast from Playa del Rey to Redondo, being especially well developed between El Segundo and Hermosa. South of Redondo a low bluff flanks the beach as far as the Palos Verdes Hills. These hills (approximate elevation 1500 feet above sea level) cause the coast line to swing westward, and are bordered by gravel beaches and rocky shore.

As this investigation is primarily concerned with the Foraminifera occurring in beach sediments, a brief outline of the more important formations found in the immediate area of Santa Monica Bay is presented in Table 1 for purposes of correlation with species of Foraminifera.

PREVIOUS WORK

The presence of Foraminifera in beach sands was a subject of study as early as 1826 when Alcide d'Orbigny investigated the "Cephalopods" of the beaches of the Adriatic Sea. In 1902, Fornasini studied the Foraminifera in the beach sand at Rimini, Italy, in far greater detail and subsequently published a comprehensive report concerning his findings. Many of these Foraminifera are now thought to have been reworked (Bandy, personal communication). Only after a lapse of some fifty years has there been a renewed interest in the foraminiferal faunas of beach sediments. Boltovskoy, in 1955, studied the Recent Foraminifera in shore sands of Quequen, Argentina, and Bhatia, in 1956, completed a detailed analysis of the Recent Foraminifera from the beaches of western India. With the exception of these studies, very little else has been done in regard to Foraminifera associated with continental type beaches. The problems of sedimentation associated with beach environments have received a good deal of study, as have the seasonal changes in beach sediments, but the seasonal changes in the faunas have not been studied.

Important work has been done in regard to the investigation of variation in living Foraminifera (Arnold, Hofker, Myers and others), but these studies have pertained to life cycles of individuals or small groups and were not primarily concerned with changes as they affect large populations over a prolonged period of time.

METHOD OF STUDY

Analysis of 210 samples was used as a basis for this study. The samples were collected weekly from each of the seven localities with a one-quart Mason jar. The method was to scrape the jar along the sand, at the swash mark, to a depth of approximately one half inch, leaving a mark about two feet long on the beach. Samples were not taken to a greater depth than one-half inch, as material below that limit may have been deposited in the intertidal zone under conditions which were different from those occurring at the time of the present sampling operation. Alcohol and the organic stain, Rose Bengal, were added to the samples (Walton, 1952, p. 60). The stain colors the protoplasm and tests of living individuals a reddish color. Empty tests of dead and reworked specimens were affected to some degree by this stain and care had to be exercised to distinguish the accuracy of this dye. However, as a rule, specimens that were not living at the time they were collected retained their original colors. When brought to the laboratory the samples were dried and weighed to the nearest tenth of a gram. Next, the Foraminifera were concentrated from the sediments by flotation in carbon tetrachloride. Representative samples of the residue were checked periodically to determine the efficiency of the separation technique. All sediment finer than 2 mm. was then analyzed by means of the sedimentation tube developed by Dr. K. O. Emery. This was used as a rapid method to determine the degree of sorting and median diameter of these samples. There was a complete absence of silt size particles, and very few of these samples contained material larger than 2 mm. The few samples that contained particles coarser than 2 mm. were screened.

Relative frequencies of the foraminiferal species were determined by counting more than 500 specimens. In no instance were the samples split more than twice by means of the Otto microsplitter and, therefore, counts of from 200 to 500 specimens were usual in many instances.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to Dr. O. L. Bandy of the University of

TABLE 1. ROCK UNITS OCCURRING IN THE AREA OF SANTA MONICA BAY
After Woodring, Bramlette & Kew, U. S. Geol. Survey, Prof. Paper 207.

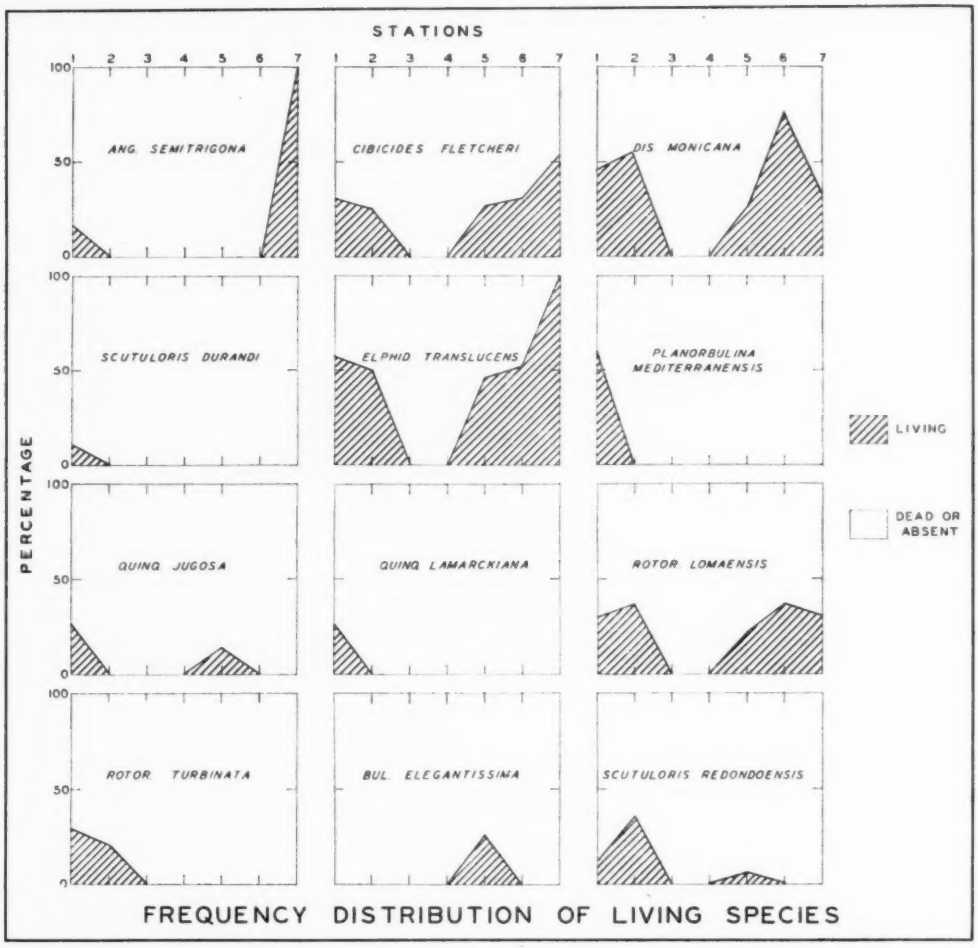
System	Series	Stage	Southwest Unit	Northwest Unit
Quaternary	Recent	—	Terrace Deposits	—
			Sand Dunes	—
	Pleistocene	Upper	Palos Verdes sand	—
		Lower	San Pedro sand	—
			Timms Point silt Lomita marl	—
Tertiary	Pliocene	Upper	—	"Pico" fm.
		Lower	Repetto siltstone	Repetto siltstone
	Miocene	Upper	Monterey Shale: Malaga mudstone	Modelo fm.
			Monterey Shale: Valmonte diatomite	
		Upper and Middle	Monterey Shale: Altamira shale	
		Middle		Topanga fm.

Southern California who suggested this project and examined the Foraminifera, as well as offered many suggestions during the course of this study. Thanks are also due to Dr. K. O. Emery who offered advice regarding the sedimentation problems, and to Drs. Bandy, Emery and Easton of the Department of Geology of the University of Southern California who read the manuscript and rendered helpful criticism.

FORAMINIFERA

LIVING FORAMINIFERA

Foraminifera living in the intertidal zone are subject to a wide range and abrupt changes in ecological conditions when compared with those living in the sublittoral zone. As a consequence of these very different conditions, few species are common to both environments. However, we find foraminiferal tests from both zones in the intertidal sediments. It is important, therefore, to be able to distinguish the species that are indigenous to the intertidal sediments from those that live only in the sublittoral zone. We should seek characteristics of morphology which indicate that certain species can adapt to sudden changes in ecological conditions and in this way establish a criterion for distinguishing intertidal species from a mixed assemblage. According to Myers (1942) the success of Foraminifera living in the intertidal zone depends largely upon their ability to make rapid readjustments to a changing environment, the protection afforded by plants living in pools and lagoons, and the ability of the Foraminifera to retain their position in this habitat against the scouring action of the surf. The selective elimination of certain groups by surf action and other adverse conditions, including the intermittent replacement of food organism by changing tides, is responsible in part for the types of tests produced by species inhibiting this zone. Species having small depressed tests that adhere closely to the substratum are not easily dislodged by currents and are free to graze upon the "microflora" that develops on most surfaces. In the investigation of the intertidal Foraminifera of Santa Monica Bay these are represented during the entire seven months of the survey, although not in the same abundance, by *Rotorbinella lomaensis* (Bandy), *R. turbinata* (Terquem), *Discorbis monicana* Za-



TEXT-FIG. *3*—Frequency distribution of living species of Foraminifera.

lesny and a few living specimens of *Trochammina pacifica* Cushman. Certain species become permanently attached to the substratum, the ventral surface of the test conforming to the surface of the algae or other object that can offer a support. The most abundant species demonstrating this ability are *Cibicides fletcheri* Galloway & Wissler, *Dyocibicides biserialis* Cushman & Valentine and *Planorbulina mediterranensis* d'Orbigny Although these species are entirely dependent upon water-borne food, they still were able to live in the intertidal area (Text-figure 3).

Other species found living in this environment are *Elphidium spinatum* Cushman & Valentine and *E. translucens* Natland, which may remain unattached and free to feed upon organisms in the substratum as well as the plankton. In addition, other abundant Foraminifera are *Buliminella elegantissima* (d'Orbigny), *Angulogerina semitrigona* Galloway & Wissler, *Quinqueloculina jugosa* Cushman, *Q. lamarckiana* d'Orbigny, *Scutuloris durandi* Cushman & Wickenden and *S. redondoensis* Reiter, n. sp. Several other species were also noted to be living in this zone, but they are represented by single

specimens and do not, therefore, make up a significant part of the fauna.

Although it was found that populations of Foraminifera in beach sands consist of many species, percentagewise many samples had 80 per cent or more individuals belonging to only two species of living Foraminifera.

DISPLACED FORAMINIFERA

> Foraminifera usually terminate their existence in one of three ways. They either reproduce, are ingested as food by larger organisms, or become buried in the sediments during periods of wind induced turbulence to a depth from which they are unable to escape (Myers, 1942).

On a sandy beach exposed to heavy surf the tests of Foraminifera are soon eroded and redeposited where there is less agitation in the water. Previous investigations have disclosed the displacement of shallow-water Foraminifera into deeper water at several locations along the California coast (Natland, 1953; Bandy, 1955). In the course of this survey it was found that there was displacement of specimens of *Streblus tepidus* (Cushman) from Playa del Rey Lagoon, but none was alive in the beach samples of this investigation. Species of *Globigerina* and a few specimens of *Lagena* were found in so excellent a state of preservation that one could conclude that these were not reworked fossil species, but had been swept in from near-shore waters during times of storm activity. The number of specimens varied during the seasons in direct relation to the conditions of the sea. Ladd (1936) in his studies at Vitilevu in the Fiji Islands observed that during periods of unusually heavy weather large numbers of pelagic Foraminifera were washed in to form an occasional Foraminifera-rich layer such as composes the Neogene Suva formation of Vitilevu, Fiji. Although *Globigerina* oozes, composed largely of the shells of pelagic Foraminifera, cover very extensive areas in modern seas at depths between 500 and 2,000 fathoms, under proper conditions they accumulate in shallower water and could conceivably form extensive deposits. Ladd concluded that the above formation composed of *Globigerina* tests could have been deposited in less than 50 fathoms of water.

REWORKED FORAMINIFERA

Due to the proximity offshore of submarine outcrops of Miocene and Pliocene sediment, and to exposures of rocks ranging in age from Miocene to Pleistocene along the terraces of Santa Monica Bay, it is reasonable to assume that Foraminifera are reworked constantly from these rocks and appear in the beach sands. This is the situation at all seven stations.

Reworked Foraminifera from Miocene strata range in age from Luisian to Delmontian (middle to upper Miocene). Recorded species include: *Bolivina granti* Rankin, *B. hughesi*, *B. goudkoffi* Rankin, B. *decurtata* Cushman *B. obliqua* Barbat & Johnson, *Uvigerina hootsi* Rankin, *U. joaquinensis* Kleinpell and *Valvulineria californica* Cushman.

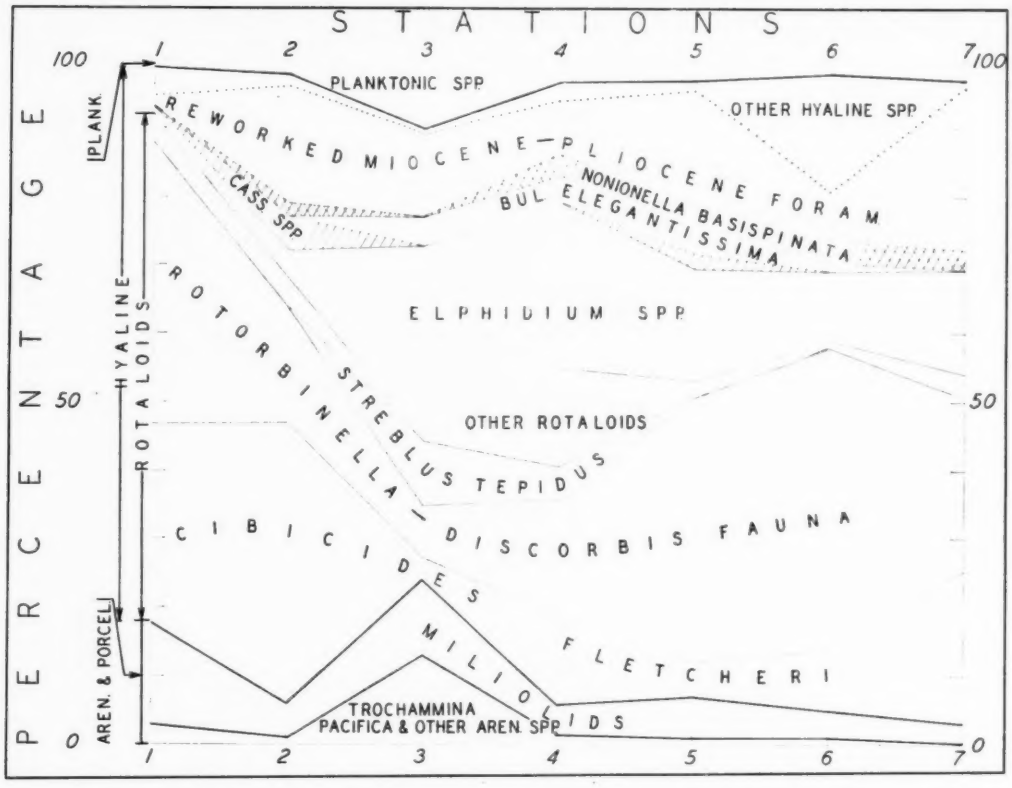
Species probably reworked from Pliocene material are: *Bolivina argentea* Cushman *B. interjuncta bicostata* Cushman, *B. sinuata* Galloway & Wissler, *Cassidulina lomitensis*, Galloway & Wissler, *C. translucens* Cushman & Hughes, *C. mckannai*, Galloway & Wissler, *Eponides tener* Martin and several other species that were only found as single specimens.

Pleistocene sediments may have contributed *Streblus tepidus* (Cushman), *Cibicides fletcheri* Galloway & Wissler and several species of *Elphidium*. However, *Cibicides fletcheri* is found living today in the intertidal zone and *Streblus tepidus* has been reported living in the area from which collections for this survey were made. Therefore, it is a matter of conjecture as to whether these forms are dead or reworked from Pleistocene sediment.

FREQUENCY DISTRIBUTION

Text-figure 4 is a chart that shows at a glance the distribution of all important groups of Foraminifera collected. Monthly patterns were combined so that an overall picture resulted from a composite of the seven collecting months.

The most striking and perhaps most noteworthy feature of this frequency distribution chart is the section concerned with reworked Foraminifera. Although more than 80 percent of the species identified from the



TEXT-FIG. 4—Chart of frequency distribution of Foraminifera.

samples are reworked Miocene-Pliocene in age, less than 25 per cent of the total number of specimens are reworked forms.

This chart shows clearly the distribution of species from the southernmost station (1) to the most westerly (7) with the increases and decreases at the intervening locations. Arenaceous, planktonic and porcelaneous species are dominant throughout the survey at station 3 and there is a corresponding decrease in the indigenous *Cibicides fletcheri* and *Rotorbinella-Discorbis* fauna. Significantly, species of *Elphidium* are abundant at this locality. A possible explanation is the exposed condition of the beach that prevents the living Foraminifera from establishing a firm foothold. This is in combination with the longshore currents depositing arenaceous, planktonic and porcelaneous Foraminifera at this point. The tests of the arenaceous and porcelaneous forms being heavier than the hyaline Foraminifera, they are not as easily winnowed from the coarser sediment found at this locality.

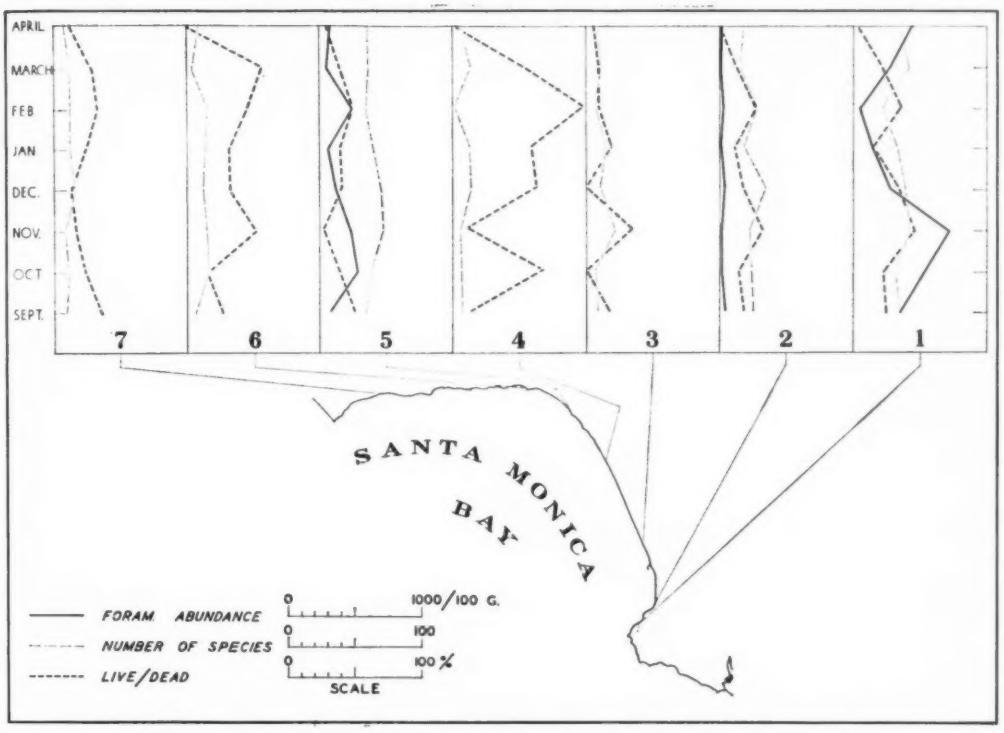
Percentage-wise the rotaloid fauna composes more than 70 percent of the hyaline group, and this is to be anticipated as most of the rotaloids are found living in this intertidal area.

SEASONAL VARIATIONS OF FORAMINIFERA

In studying samples from the same localities collected on a weekly basis, it is possible to observe very minute changes in abundance of foraminiferal populations. Definite increases and decreases could be correlated with seasonal changes. During the months of September, October and early November, there were large numbers of specimens and a corresponding increase

in the number of species. For the next several months (December, January, February and March) there was a gradual decrease in abundances, especially noticeable during storm periods. In April, the last month of the survey, a more stable condition developed and slight increases were noticed (Text-figure 5).

As there were only two moderately severe storms (December 7, 1956 and March 10, 1957) during the period of the survey, the overall cause of the winter decrease in Foraminifera is not wholly the result of heavy wave action that usually prevails at this season of the year. Rather, as far as the living Foraminifera are concerned, it is based very largely on the temperature change of the sea water and its subsequent effect on the rate of reproduction. Experiments by Myers (1935) concerning the life history of *Patellina corrugata* Williamson demonstrated that, under laboratory conditions, the maximum rate of reproduction occurred at 21°C. Below 18°C. the rate of reproduction was greatly retarded. He arrived at the conclusion that reproduction in the sea is limited almost exclusively to the warm summer months. Unfortunately, representative samples were not available for the period (May through August), when the sea water temperature is the highest (over 21°C.). However, in September the average water temperature at the collecting points was slightly above 19°C. and this contrasted with a water temperature of approximately 15°C. in December. (See data sheets, Table 7). The temperature was never above 19°C. after September and this gives credence to the contention that a decrease in number of Foraminifera may be due in large part to the temperature affecting the rate of reproduction. This would account for the seasonal variations in abundance of living Foraminifera. The wave activity would be a



TEXT-FIG. 5—Seasonal variation in abundance, number of species and live/dead ratio of Foraminifera.

contributing factor affecting the number of displaced and reworked Foraminifera.

NUMBER OF SPECIES

Table 2 lists the number of species found at each station for the months of September through April (1956–1957). A graphic representation of these numbers is shown in Text-figure 5. Note the more diversified populations at the protected stations (1 and 5) than at the other localities. This same trend will appear again in the discussion of the abundance of Foraminifera.

TABLE 2—NUMBER OF SPECIES OF FORAMINIFERA FOUND AT EACH STATION FOR THE MONTHS OF SEPTEMBER 1956 THROUGH APRIL 1957

Months	Stations						
	1	2	3	4	5	6	7
September	37	25	9	8	35	6	10
October	32	22	8	7	39	15	12
November	43	21	21	7	49	15	9
December	39	34	11	13	46	11	17
January	32	18	14	12	40	13	11
February	21	28	9	1	34	15	11
March	40	15	10	13	36	4	11
April	36	18	9	7	36	8	8
Total	280	181	91	68	314	87	89

SEDIMENTS

In previous studies by other workers it was determined that wave turbulence is the controlling factor in concentrating sediment of a grain size larger than 0.125 mm. available for transportation along the coast. Changes in beach profile were correlated not as much with the tidal cycles as with the amplitude of the waves. As the waves increased in size, the sand was moved in both directions away from the region near the plunge point. As the waves diminished in size, the sand moved back, reestablishing the original profile. It was brought out that practically all, if not entirely all, of the sea beaches along the exposed southern California coast are composed predominantly of sediments of a grain size larger than 0.125 mm. Finer grained material appears to have a settling rate in sea water too slow in relation to wave turbulence to be able to remain on the exposed beaches. Large amounts of fine-grained sediment may be carried out by rip currents and these currents may account for the lack of sediment finer than 0.125 mm. being found in appreciable quantities along the shore of Santa Monica Bay (Shepard, Emery, La Fond, 1941).

For the purpose of greater clarity, the results of the analysis of the Foraminifera-bearing sediments collected during the course of this investigation are presented in tabular and graphical form in the following pages. In general it may be stated, however, that the sand at all the stations was very well sorted (average 1.77 mm.). It had an over-all average median diameter of .432 mm. that varied only slightly during the collecting seasons (Text-figure 6). It is also brought out in Tables 4 and 5 that the sediment did not vary in size according to the seasons. The coarsest sands were not restricted to the

TABLE 3—STATISTICAL RESULTS OF BEACH ANALYSIS FOR PERIOD SEPTEMBER 22, 1956 TO APRIL 18, 1957*

Station Number	Sorting Coefficients (mm.) Trask	Median Diameters (mm.)
1	1.81	.675
2	1.78	.571
3	1.77	.383
4	1.56	.435
5	1.76	.251
6	1.67	.361
7	1.68	.312

* Based on 30 samples per station.

TABLE 4. MAXIMUM SEASONAL VARIATIONS IN SAND SIZE (MEDIAN DIAMETERS)

Station Number	Date	Median	Date	Median
1	11/ 3/56	1.950	9/29/56	.130
2	3/16/57	1.550	10/ 6/56	.180
3	9/29/56	1.100	1/12/57	.190
4	10/ 3/56	.510	11/17/56	.315
	11/24/56		2/16/57	
5	12/28/56	.540	10/13/56	.110
			10/20/56	
			11/17/56	
			2/16/57	
6	10/ 6/56	1.100	2/16/57	.195
7	2/ 1/57	.490	9/29/56	.175
			12/28/56	
			2/16/57	

TABLE 5—MAXIMUM SEASONAL VARIATIONS IN SORTING COEFFICIENTS

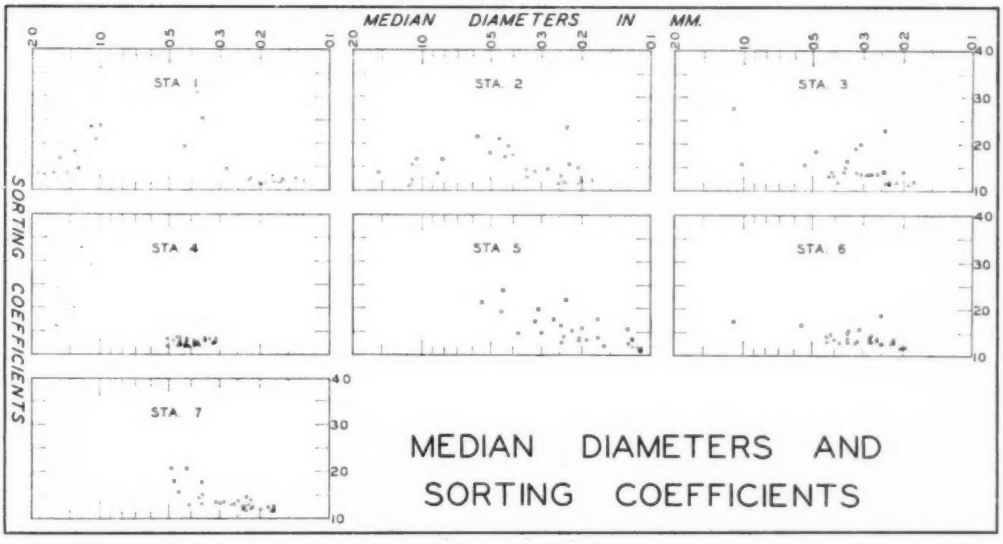
Station Number	Poorest Sorting		Best Sorting	
	Date	Sorting Coefficient	Date	Sorting Coefficient
1	2/23/57	3.10	12/28/56	1.10
2	12/28/56	2.30	10/27/56	1.10
3	9/29/56	2.75	2/16/57	1.15
4	11/17/56	1.40	11/24/56	1.15
5	12/ 7/56	2.35	11/17/56	
			2/16/57	1.10
6	10/13/56	1.85	12/28/56	1.19
			2/16/57	
7	1/18/57	2.05	1/12/57	1.17
	1/ 1/57			

winter and spring months, but were formed more in relation to the storm periods.

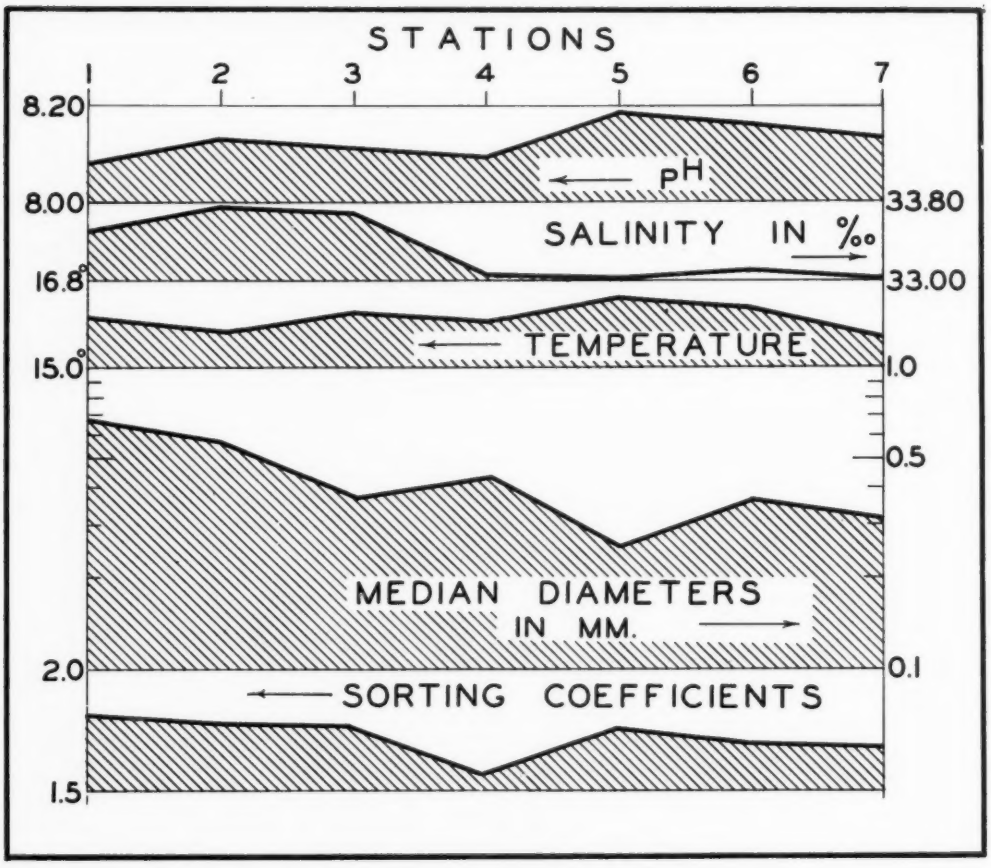
SEDIMENT-FORAMINIFERA RELATIONSHIPS

General Analysis of Stations.—The stations located along the margin of Santa Monica Bay are designated numbers 1, 2, 3, 4, 5, 6 and 7 respectively, from south to north (Text-figure 2). Station 1 is located at Bluff Cove, Palos Verdes Hills, and is the southernmost station, representing an area most similar to one found in a tide pool type of environment. It is a pocket beach with headlands forming its northern and southern limits. The beach itself is protected from direct wave action by the presence of heavy accumulations of kelp. Both living and dead Foraminifera were found in abundance in this area, with *Rotorbinella lomaensis* (Bandy) and *Cibicides fletcheri* Galloway & Wissler most characteristic of the fauna. Due in large measure to the protection afforded by the headlands and the kelp beds, the number and types of species remained constant throughout the course of this survey. The sediment of the beach had an average median diameter of 0.675 mm. and a sorting coefficient of 1.81 mm. (based on 30 samples). The temperature, pH, and salinity were fairly constant throughout the seasons (Text-figure 7). It is believed that the Foraminifera found at this locality that assumed a red stain upon addition of the Rose Bengal dye were living in the sediment, and that the few reworked species were derived directly from the exposed outcrops of Miocene strata along the shore and immediately offshore.

Station 2 is two and one-half miles to the north of Bluff Cove and two miles south of the head of Redondo Canyon (which approaches to within a few hundred yards of the beach at Redondo). This is an open stretch of coast-line affected by longshore



TEXT-FIG. 6—Plot of median diameters and sorting coefficients of sediments.



TEXT-FIG. 7—Complete chart of pH, salinity, water temperature, median diameters and sorting coefficients.

currents moving in a northwesterly direction around the Palos Verdes headland. The presence of a canyon to the north and a northwest current (current flow is southeast at stations 3, 4, 5, 6 and 7) enables this locality to be used as a comparison point for correlation with locations to the north. The dominant species were again *Rotorbinella lomaensis* (Bandy) and *Cibicides fletcheri* Galloway & Wissler; however, the number of living specimens showed a reduction compared to station 1. There was a subsequent increase in the number of dead and reworked Foraminifera. Foremost among reworked species was *Uvigerina peregrina* Cushman from the Pliocene. There are no intermittent streams in this area and very little material is contributed from the marine terraces adjacent to the beach. Due to the exposed position of the beach there were wide seasonal variations in number and types of Foraminifera. The average median diameter of the sand was 0.571 mm. and the sorting coefficient was 1.78 mm. An increase in both the pH and salinity was noted, and a decrease in the water temperature also occurred during this survey as compared with station 1.

Station 3, between Hermosa Beach and Manhattan Beach, is five miles north of Station 2 and three miles to the north of the head of Redondo Canyon. The current direction at this point, as well as at the remaining four stations, is to the southeast. The coastline continues to be open and exposed to wave action from both the north and southwest. There is a marked decrease in the

number of Foraminifera found at this locality, most of the species being reworked forms, some specimens of *Uvigerina peregrina* Cushman and the first appearance of a displaced *Streblus tepidus* (Cushman) fauna. Practically no living Foraminifera were noted, and the dead forms in most instances were badly broken and worn, due in large measure to the exposed condition of the beach. Lack of natural or artificial barriers prevented the accumulation of Foraminifera at this point. The average median diameter of the sediment is 0.383 mm. and the sorting coefficient is 1.77 mm. The pH, salinity and water temperature remained fairly constant throughout the survey, with only a slight variation in the pH due to increased rainfall. There are no intermittent streams contributing sediment to this area and it is, therefore, believed that the source of Foraminifera is the exposed Miocene-Pliocene formations located immediately offshore.

Station 4, or the Playa del Rey locality, is situated seven miles north of point 3 and lies adjacent to the north end of the Ballona Creek rock jetty. Material carried along the coast from the north is blocked by this artificial obstacle and, therefore, this fauna should show a difference from faunas collected at stations to the south. Unfortunately, the number of Foraminifera collected here is extremely small and practically all consist of single specimens of reworked species. Very few living Foraminifera were found in this area. The entrance of Ballona Creek to the bay provides a negligible amount of new material, as most of the load of the creek is deposited in Ballona Lagoon before entering the bay. Specimens of *Strebulus tepidus* (Cushman) are reported living in the lagoon and their appearance in the beach sands here and to the south may be explained by their transportation to the beach during storms and their movement southward by longshore currents. The average median diameter of the sand is 0.435 mm. with a sorting coefficient of 1.56 mm., one of the best sorted of all the locations and one which has maintained this sorting throughout the study (Text-figure 6). The pH and salinity show a gradual decrease at this station in comparison to points farther to the north. The water temperature remained constant.

Station 5, near the City of Santa Monica, is a distance of four and one-quarter miles to the north of station 4. This area is characterized by the presence of a rock jetty parallel to the shore and about one-quarter mile from the beach, and a sand spit to the north formed by the southeast longshore current. An embayment is the result of these two factors. This area is extremely prolific in the number and variety of species produced. *Rotorbinella lomaensis* (Bandy) is found in abundance both living and dead. For the first time there is an appearance of many reworked *Bolivina* spp., as well as *Elphidiums* and *Cassidulina*. *Uvigerina* spp. also make up an important percentage of the reworked fauna. The ages of the *Bolivina* and *Cassidulina* Foraminifera suggest the presence of outcrops of Miocene strata offshore. The average median diameter of the sand is 0.251 mm. and it is the finest at any station. The sorting coefficient is 1.76 mm., and it was fairly constant during the seasons in which the collections were made. The pH, salinity and water temperature all remained constant.

Station 6, four and nine-tenths miles northwest of station 5, presents a different environmental situation than the previous locations. This area is a narrow exposed, rocky beach interspersed with large conglomeratic boulders derived by landslides from the adjacent marine terrace. Material also is brought to the beach by intermittent streams entering the bay at Topanga Canyon to the north and carried by the southeast flowing longshore current. In addition, a moderately severe surf was observed during the survey, and this greatly reduced the number of Foraminifera. With the exception of *Rotorbinella lomaensis* (Bandy) and *Cibicides fletcheri* Galloway & Wissler there was an absence of living species. The only other species collected at this point were occasional reworked Miocene species never numbering over 20 specimens per sample. The average median diameter of the same was 0.361 mm., with a sorting coefficient of 1.76 mm. As was the case at the other stations, the pH, salinity and water temperature remained fairly constant during the collecting seasons.

Station 7 is the westernmost of the beaches studied. It is approximately two

miles west of the town of Malibu and ten miles from station 6. This wide crescent shaped beach is in the lee of Point Dume to the west, and of the Santa Monica Mountains on the north. It is, therefore, notably affected only by storm winds which come from the south. *Rotorbinella lomaensis* (Bandy) and *Cibicides fletcheri* Galloway & Wissler again constitute the only living Foraminifera found at this locality. Several species of *Uvigerina*, evidently reworked from offshore, and a heterogeneous group of individual species numbering less than 20 specimens make up the balance of the fauna. The average median diameter of the sand is 0.312 mm., with a sorting coefficient of 1.68 mm. Salinity and pH remained fairly constant; however, the lowest average water temperature of 15.6°C. occurred at this station.

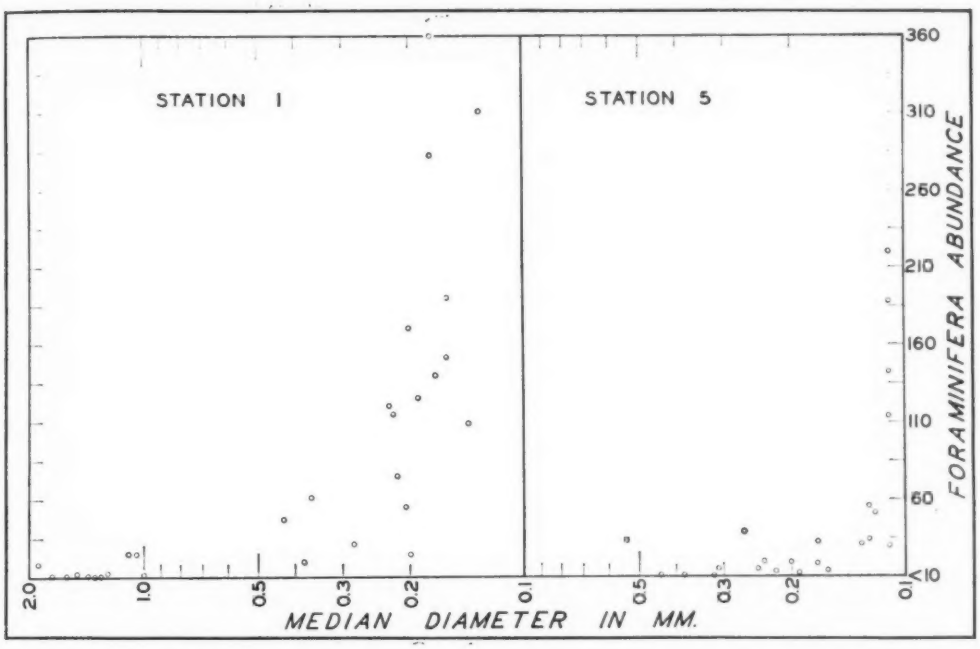
Foraminiferal Abundance per 100 Grams of Sediment.—The number of specimens in each sample was estimated as closely as possible by splitting each sample until an easily countable fraction was obtained. This fraction was then counted and multiplied by the number of splits taken which gave the total of Foraminifera in each sample. This total was then divided by the number of grams of processed sediment which gave the number of Foraminifera per gram of sediment. Inasmuch as the sediment collected amounted to more than 400 grams in all samples, the per gram figure was multiplied by 100, in order to be able to work with whole numbers rather than fractions of Foraminifera. This process was repeated for each of the seven stations studied. It is interesting to note from Table 6 that from 8 to 50 times or more specimens were collected at protected stations (1 and 5) as compared with unprotected stations.

Seasonal Variations in Abundance of Foraminifera Versus Median Diameter of Sediment.—When the foraminiferal abundance for the seven collecting months of this survey is contrasted with the median diameter of the sediment, an interesting result is immediately apparent. There exists an inverse relationship between the size of the sand grains (median diameter) and the number of foraminiferal specimens in the sample. As the median grain size increases to approximately 0.500 mm., there is a proportional decrease in the number of Foraminifera. With a decrease in the median grain size below 0.500 mm., there is a subsequent increase in the number of specimens. This relationship is most apparent at stations 1 (Palos Verdes Hills) and 5 (Santa Monica). These are not isolated instances but occur with regularity for each sample (Textfigures 8, 9 and 10).

A logical explanation for the relationship of abundance of Foraminifera with median grain size is the settling rate of the tests of the Foraminifera. These tests are in most instances in the same grade range as the sand in which they are found and, therefore, would remain with the sand less than 0.500 mm. In the coarser sand the tests would be winnowed from the sediment and subsequently redeposited at a lower point on the beach exposed at times of low tide. This has proved to be the case, as the finer sediment is collected at times of low tide and contains

TABLE 6—NUMBER OF SPECIMENS OF FORAMINIFERA FOUND AT EACH STATION FOR THE MONTHS OF SEPTEMBER 1956 THROUGH APRIL 1957

Month	Stations						
	1	2	3	4	5	6	7
September	343	30	1	2	86	1	8
October	531	15	2	2	292	12	8
November	717	17	12	1	233	8	2
December	289	34	5	5	114	5	16
January	159	13	9	6	63	14	2
February	47	25	7	0	244	10	7
March	286	6	2	5	62	2	3
April	431	14	2	1	80	3	5
Totals	2803	154	40	22	1164	55	51



TEXT-FIG. 8—Plot of abundance of Foraminifera versus median diameter of sand, stations 1 and 5.

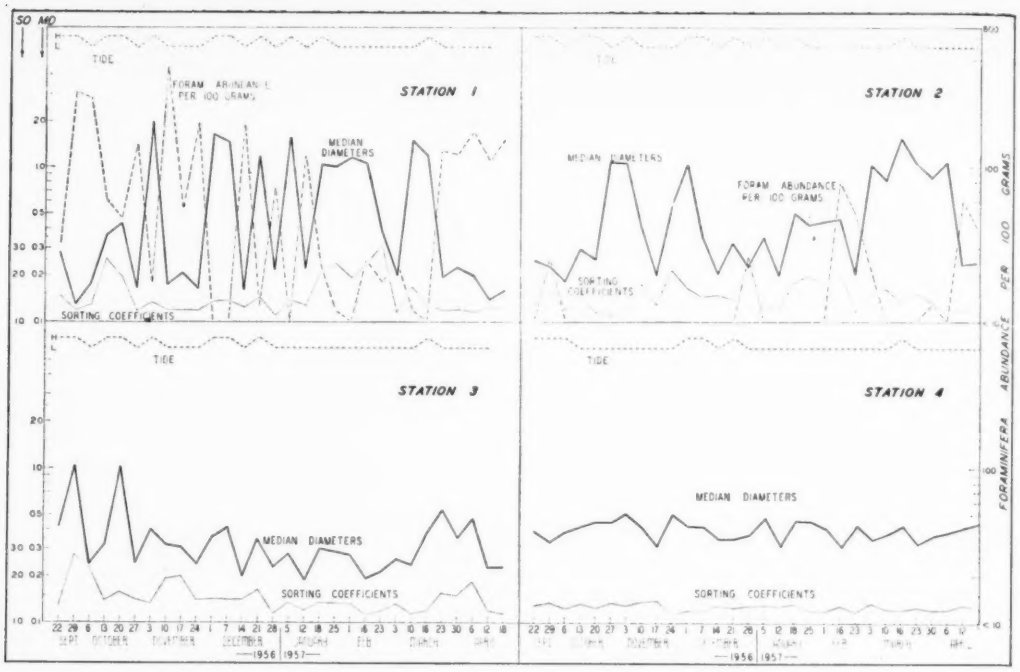
the greatest abundance of Foraminifera.

Natland (1953) made a very interesting study of relationships of abundance of Foraminifera to rate of sedimentation. In this he found that off Catalina Island, approximately 90 percent of the sediment from his Zone III was composed of Foraminifera and shell fragments and about 10 percent was composed of silt. In Zone III off Long Beach the converse was true. Most of the Foraminifera in Zone III off Long Beach were alive or had not been lying on the bottom for a long period of time, judging from their preservation when dredged. Evidently, they were being covered with sediment as fast as they were accumulating. But off Catalina, where the specimens are very abundant, only 5 or 10 percent were living; the other tests were badly worn or broken, indicating that they had been lying uncovered on the bottom for a long time. Thus, Natland, as well as other authors, suggests that the rate of sedimentation is much slower off Catalina than off Long Beach, which is to be expected. The conclusion is that, other factors being equal, the rate of sedimentation largely controls the abundance of Foraminifera. As a result of the analysis of the intertidal area of Santa Monica Bay, these ideas could be expanded so that it would be possible to interpret, by the comparative abundances of Foraminifera, the conditions of sedimentation and approximate grain size distribution for a given period of time.

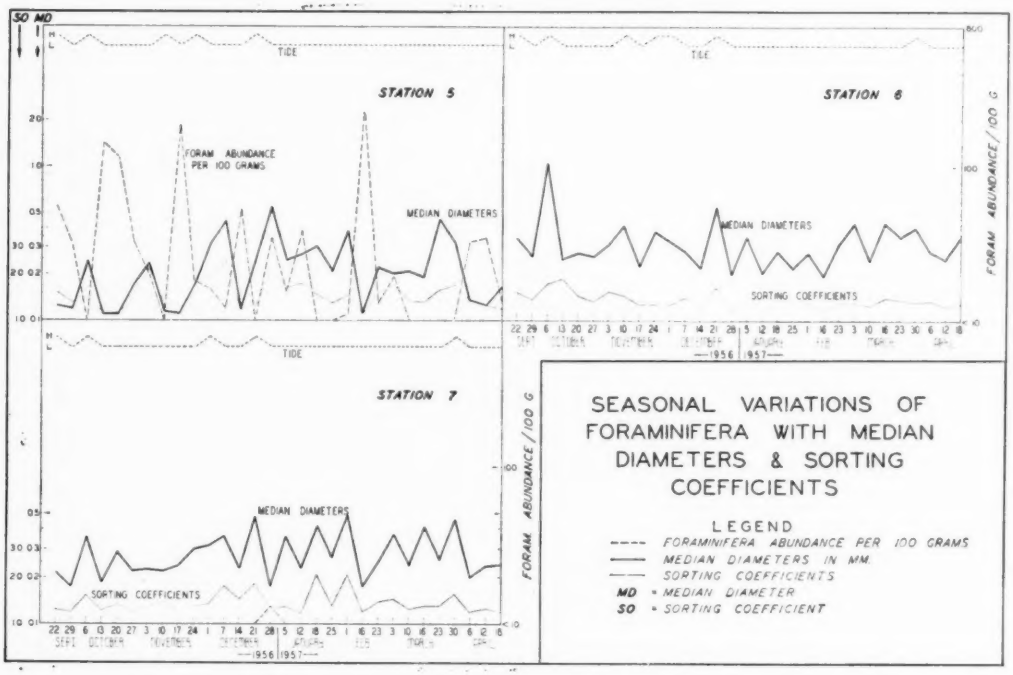
SUMMARY AND CONCLUSIONS

One of the foremost problems in this study is the proper interpretation of the factors causing a seasonal variance. They may be the changes in the sediment in which the Foraminifera live, the change in the life cycles of the fauna, and the changes in the temperature of the sea water brought about by climatic conditions and ultimately affecting the life processes of the Foraminifera. In this investigation not one, but many factors are offered.

One of the primary problems is the origin of the Foraminifera found in the unlikely environment of the intertidal zone. The reworked Foraminifera can be accounted for by the presence of near-shore outcrops of Miocene-Pliocene age sediments and Pleis-



TEXT-FIG. *9*—Seasonal variation of Foraminifera with median diameters and sorting coefficients of sediment, stations 1–4.



TEXT-FIG. *10*—Seasonal variation of Foraminifera with median diameters and sorting coefficients of sediment, stations 5–7.

TABLE 7—DATA SHEETS

Data	Station Number						
	1	2	3	4	5	6	7
September 22, 1956							
Water temp.	17	17	19	18	—	—	—
pH	—	—	—	—	—	—	—
Gram Wt.	711.5	751.3	746	675.4	448	663.8	609.9
September 29, 1956							
Water temp.	20	19.5	20	20	23	22	20
pH	7.8	8.0	8.0	8.0	8.2	8.1	8.1
Gram Wt.	562.2	692.4	753.5	667	598.5	645.5	531.4
Tide	High	High	High	High	Low	Low	Low
October 6, 1956							
Water temp.	19.5	19.5	19.5	19.5	18	18	17.5
pH	8.0	8.1	8.0	8.1	8.2	8.0	8.9
Gram Wt.	540	641	651	693.4	602.8	704.2	726.6
Tide	Low	Low	Low	High	High	High	High
October 13, 1956							
Water temp.	17.5	17.5	18.5	18.0	18.5	19.5	18.0
pH	7.8	7.9	8.0	7.95	8.0	8.0	8.1
Gram Wt.	691.1	676	530.4	706.5	462.5	575	452.7
Tide	High	High	High	Low	Low	Low	Low
October 20, 1956							
Water temp.	15.0	15.5	16.0	18.0	18.0	18.5	19.0
pH	—	8.1	8.0	8.0	8.2	8.0	8.0
Gram Wt.	685.5	615.5	721.5	644.5	491.5	495.9	566.8
Tide	High	High	High	High	Low	Low	Low
October 27, 1956							
Water temp.	16.2	16.8	16.8	16.4	16.0	16.6	16.2
pH	7.8	8.1	7.9	7.7	8.1	8.1	8.1
Gram Wt.	552	692.5	570.8	669.2	532.3	561.2	559.1
Tide	Low	Low	Low	Low	Low	Low	Low
November 3, 1956							
Water temp.	12.4	12.8	14.1	14.9	15.9	14.9	12.9
pH	7.8	7.95	8.0	8.0	8.1	8.2	7.9
Gram Wt.	794.9	742.5	640.1	532.5	652.7	549.9	515
Tide	High	High	High	Low	Low	Low	Low
November 10, 1956							
Water temp.*	15.3	15.1	15.3	15.4	16.2	16.0	15.4
pH	—	—	—	—	—	—	—
Gram Wt.	552	701.5	615.5	693	615.9	680.5	548.2
Tide	Low	Low	Low	Low	High	High	High
Salinity	32.1	—	—	—	33.3	—	31.7

* Air temperature for week ending November 10, 1956 was between 90° and 95° Fahrenheit.

TABLE 7—(*Continued*)

Data	Station Number						
	1	2	3	4	5	6	7
November 17, 1956							
Water temp.	16.8	16.4	16.2	17.1	17.2	16.8	16.9
pH	—	—	—	—	—	—	—
Gram Wt.	597.7	682.5	666.6	625.7	457	531.5	658.2
Tide	Low	Low	Low	Low	Low	Low	Low
November 24, 1956							
Water temp.	16.0	15.8	16.1	16.2	16.2	16.1	16.0
pH	—	—	—	—	—	—	—
Gram Wt.	559.6	692.4	626.1	610.6	492.8	571.9	653
Tide	Low	Low	Low	Low	High	High	High
Salinity	—	—	—	—	—	—	33.4
December 1, 1956							
Water temp.	14.8	15.2	15.4	15.5	16.2	15.3	14.5
pH	—	—	—	—	—	—	—
Gram Wt.	809.3	803.7	709.5	715.7	631.6	482	489.4
Tide	High	High	High	High	Low	High	High
December 7, 1956†							
Water temp.	15.3	15.2	15.5	15.2	14.8	15.1	15.1
pH	8.05	8.2	8.2	8.2	7.9	8.1	8.2
Gram Wt.	758.6	727.8	674.8	581	642.5	480.8	501
Tide	High	High	High	High	Low	Low	Low
Sea	Rough	Rough	Rough	Rough	Rough	Calm	Calm
December 14, 1956							
Water temp.	16	15.6	15.7	15.6	16.1	15.5	15.6
pH	—	—	—	—	—	—	—
Gram Wt.	487	712	585.6	599.5	433.6	631.6	670.9
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
Salinity	33.8	33.8	33.7	33.4	33.6	33.4	33.7
December 21, 1956							
Water temp.	14.7	14.9	15.1	14.9	15.1	15.0	15.0
pH	—	—	—	—	—	—	—
Gram Wt.	756.8	759.8	590.2	585.8	666.2	431.3	554.5
Tide	High	High	High	High	High	High	High
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
December 28, 1956							
Water temp.	15.0	14.8	14.6	15.0	15.8	15.7	15.3
pH	7.9	7.9	7.9	8.0	8.1	8.2	8.2
Gram Wt.	598.9	458.6	625.5	625.4	501	538.5	529.1
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm

† Storm.

TABLE 7—(*Continued*)

Data	Station Number						
	1	2	3	4	5	6	7
January 5, 1957							
Water temp.	15.2	15.2	15.7	15.1	15.1	15.1	15.0
pH	—	—	—	—	—	—	—
Gram Wt.	790	803.6	513.5	552.1	690	586.9	533
Tide	High	High	High	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
January 12, 1957							
Water temp.	14.6	14.9	15.1	14.8	14.9	14.7	14.6
pH	—	—	—	—	—	—	—
Gram Wt.	564.5	617.4	482.2	554.3	640	474.3	671.1
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
January 18, 1956							
Water temp.	13.5	14.5	14.9	15.0	15.7	15.2	15.0
pH	—	—	—	—	—	—	—
Gram Wt.	559.8	457	573.3	472.4	562.5	468.9	681.8
Tide	High	High	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
January 26, 1957							
Water temp.	13.8	13.1	14.1	13.7	14.0	14.0	13.7
pH	8.1	81.	8.0	8.1	8.1	8.1	8.2
Gram Wt.	801.4	648.8	670.6	700.5	514.4	542.4	661.4
Tide	Low	Low	Low	Low	Low	Low	Low
Salinity	33.8	33.7	33.4	31.2	33.5	33.5	33.5
Sea	Rough	Rough	Rough	Rough	Rough	Rough	Rough
February 1, 1957							
Water temp.	13.0	13.1	13.4	12.8	13.9	13.8	13.7
pH	—	—	—	—	—	—	—
Gram Wt.	795.1	690.6	525.9	545.6	651.0	607.7	701.6
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
February 10, 1957							
Water temp.	—	—	—	—	—	—	14.5
pH	—	—	—	—	—	—	—
Gram Wt.	—	—	—	—	—	—	593.6
Tide	—	—	—	—	—	—	Low
Sea	—	—	—	—	—	—	Calm
February 16, 1957							
Water temp.	14.1	14.1	14.1	14.3	14.9	15.0	14.7
pH	—	—	—	—	—	—	—
Gram Wt.	510	428.3	341	418.4	325.4	471.3	356.4
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm

TABLE 7—(*Continued*)

Data	Station Number						
	1	2	3	4	5	6	7
February 23, 1957							
Water temp.	14.3	14.3	15.2	14.5	16.0	15.9	14.8
pH	7.8	7.7	7.8	7.6	8.0	7.6	7.6
Gram Wt.	775.5	731.2	530.5	614	656.7	678.4	499
Tide	Low	Low	Low	Low	Low	Low	Low
Salinity	33.5	33.4	33.5	32.9	21.0	31.3	33.0
Sea	Choppy	Choppy	Choppy	Choppy	Choppy	Choppy	Choppy
March 3, 1957							
Water temp.	17.0	15.9	15.4	15.5	16.7	15.7	15.3
Gram Wt.	594.7	774	664.3	666.6	632.7	664.4	535
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
March 10, 1957							
Water temp.	15.5	15.4	15.5	15.7	16.7	16.4	15.4
Gram Wt.	806.1	786.7	599.7	716.4	652.6	516.4	522
Tide	Low	Low	Low	Low	Low	Low	Low
Sea†	Rough	Rough	Rough	Rough	Rough	Rough	Rough
March 16, 1957							
Water temp.	14.7	14.8	15.1	14.1	14.7	14.3	13.8
Gram Wt.	707.6	829	623.9	727.2	638.1	613.7	633.9
Tide	High	High	High	High	Low	Low	Low
Sea	Choppy	Choppy	Choppy	Choppy	Choppy	Choppy	Choppy
March 23, 1957							
Water temp.	17.5	14.0	14.5	13.0	13.6	15.4	13.8
pH	8.5	8.0	8.0	7.9	7.9	8.1	7.9
Gram Wt.	629	585.1	681	568.6	649.6	634.5	530.1
Tide	Low	Low	Low	Low	Low	Low	Low
Salinity	33.8	33.9	33.8	33.9	33.9	34.0	34.0
Sea	Calm	Calm	Calm	Calm	Calm	Choppy	Choppy
March 30, 1957							
Water temp.	18.0	16.4	16.3	16.0	15.8	15.0	14.4
Gram Wt.	576.2	751.1	676.3	644.5	647.0	656.0	597.9
Tide	Low	Low	Low	Low	Low	High	High
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
April 6, 1957							
Water temp.	14.7	14.7	14.6	14.1	14.5	14.1	13.6
Gram Wt.	584.4	634.0	707.7	691.2	558.7	618	664.4
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm

† Tidal wave—earthquake in Aleutian Islands on March 9, 1957.

TABLE 7—(*Continued*)

Data	Station Number						
	1	2	3	4	5	6	7
April 12, 1957							
Water temp.	19.8	16.5	17.6	16.3	17.5	16.9	16.0
Gram Wt.	582.6	732.7	657.3	709	501.3	706.7	689.5
Tide	Low	Low	Low	Low	Low	Low	Low
Sea	Calm	Calm	Calm	Calm	Calm	Calm	Calm
April 18, 1957							
Water temp.	15.1	15.1	15.5	14.9	15.7	15.0	14.0
pH	8.3	8.3	8.3	8.2	8.0	8.2	8.1
Gram Wt.	610.3	756.7	718.8	615	608.2	724.1	657.3
Tide	Low	Low	Low	Low	Low	Low	Low
Salinity	33.7	33.7	33.8	33.5	32.4	33.3	31.3
Sea	Calm	Choppy	Choppy	Choppy	Choppy	Choppy	Choppy

tocene strata in the adjacent terraces. These rocks are the logical source areas for the reworked Foraminifera being supplied to the beach sands through wave and current action, with large influxes of reworked forms noted after periods of moderately severe storms. Displaced pelagic fauna such as *Globigerina* that occur in these sediments can conceivably be brought also to the beaches by increased wave activity supplemented by the action of the longshore current. Many species of Foraminifera have adapted to the intertidal environment and appear to flourish in this very restricted area. Species of *Rotorbinella*, *Discorbis*, *Cibicides*, *Quinqueloculina* and *Buliminella* are found to be living in these beach sands, undergoing only a variation in abundance during the seasons. In addition to the living fauna, tests of Foraminifera that were not alive when collected could reasonably be assumed also to have lived in this environment. Tests of

TABLE 8—SUMMARY OF DATA AVERAGES

Average	Station Number						
	1	2	3	4	5	6	7
pH	8.1	8.1	8.1	8.1	8.1	8.1	8.1
Water temp.	16.0	15.7	16.1	15.9	16.4	16.2	15.6
Salinity	33.5	33.8	33.7	33.1	33.0	33.2	33.0
Md.	.67	.57	.38	.43	.25	.36	.3
So.	1.8	1.8	1.8	1.6	1.8	1.7	1.7

Total Average pH all stations	8.12
Total Average Temp. all stations	16.0
Total Average Salinity all stations	33.38
Total Average Md. all stations	.43
Total Average So.	1.77

Distance between Stations in Miles

Station Number						
1	2	3	4	5	6	7
	2.4	5.0	7.0	4.4	4.9	10.2

TABLE 9—FORAMINIFERA PERCENTAGES

SPECIES	Station Number						
	1	2	3	4	5	6	7
Alveolophragmium columbiensis Cushman	—	—	1.3	—	—	—	—
Gaudryina subglabrata Cushman & McCulloch	1.0	—	—	—	—	—	—
Trochammina pacifica Cushman	1.4	—	12.0	1.6	—	—	—
TOTAL ARENACEOUS	3.0	1.0	13.0	1.6	1.0	1.0	—
Quinqueloculina akneriana d'Orbigny	—	—	9.5	1.0	3.6	1.0	1.0
Quinqueloculina angulo-striata Cushman & Valentine	1.0	—	—	—	—	—	—
Quinqueloculina jugosa Cushman	2.3	1.0	—	1.6	1.0	—	—
Quinqueloculina lamarckiana d'Orbigny	3.0	—	—	—	—	1.0	—
Quinqueloculina rhodiensis Parker	4.0	1.0	—	—	—	—	—
TOTAL QUINQUELOCULINE	10.3	2.0	9.5	2.6	4.6	2.0	1.0
Scutuloris redondoensis Reiter	1.6	1.5	—	1.0	2.0	1.0	1.3
Scutuloris durandi (Cushman & Wickenden)	1.8	—	—	—	—	—	—
TOTAL PORCELLANEOUS	14.8	5.0	11.0	4.0	6.0	4.0	3.0
Cibicides fletcheri Galloway & Wissler	29.0	41.0	3.2	13.0	5.2	9.0	22.3
Discorbis monicana Zalesny	7.0	1.4	2.3	15.1	10.0	15.0	9.2
Rotorbinella lomaensis (Bandy)	34.0	15.4	5.4	15.0	28.4	29.0	16.2
Streblus tepidus (Cushman)	—	—	9.5	4.8	.4	—	—
TOTAL ROTALOID	74.3	62.1	20.8	49.2	46.2	54.1	51.3
Elphidium microgranulosum Galloway & Wissler	1.0	1.0	5.0	1.0	8.0	—	12.0
Elphidium translucens Natland	1.1	2.0	16.0	17.0	7.4	10.0	3.1
Elphidium hughesi Cushman & Grant	—	1.0	6.8	6.3	1.0	—	—
Cassidulina spp.	—	5.1	—	—	2.2	—	—
Buliminella elegantissima (d'Orbigny)	—	—	4.5	4.0	4.3	1.3	—
Nonionello basispinata Cushman & Moyer	—	2.1	—	3.2	3.2	3.4	3.1
TOTAL HYALINE	81.2	92.0	66.0	91.0	90.0	93.0	94.0
REWORKED FORAMS (included with Hyaline totals)							
Uvigerina peregrina Cushman	—	7.4	8.6	4.0	7.0	1.4	9.6
Uvigerina joaquinensis Kleinpell	1.0	—	—	—	—	—	—
TOTAL REWORKED	1.6	17.0	15.0	8.0	16.2	7.0	24.0
Globigerina bulloides d'Orbigny	—	2.0	5.0	—	—	—	2.1
Globigerina concinna Reuss	—	—	3.2	3.0	2.1	1.4	—
Globigerina subcretacea Chapman	1.0	—	1.0	1.0	—	—	—
TOTAL PLANKTONIC	1.0	2.0	10.0	3.2	3.0	2.0	3.0

Quinqueloculina were found in abundance and several species could have been alive prior to collecting. The explanations for the Foraminifera indigenous to this zone are numerous; however, it is believed that the adaptation of the tests, permitting them to secure a firm attachment to the substratum and to the algae that is present in the area is one of the prime requisites. Their seasonal variations in abundance are due, in large measure, to the changes in the sea water temperature in the fall and winter months. As the temperature drops below 21°C., the rate of reproduction is subsequently restricted. This does not mean, of course, that they reproduce only at times of abnormally

TABLE 10—LIVING/DEAD RATIO

Month	Number Living	Number Dead	Total	Per Cent
Station 1				
September	568	1,497	2,065	27.5
October	632	2,280	2,912	21.7
November	1,858	2,205	4,063	45.7
December	560	976	1,538	36.4
January	145	806	951	15.2
February	109	192	301	36.2
March	383	1,393	1,776	21.5
April	132	2,688	2,820	4.7
Total	4,387	12,037	16,424	26.7
Station 2				
September	34	145	179	19.0
October	13	73	86	15.1
November	37	77	114	32.4
December	33	145	178	18.5
January	7	51	58	12.0
February	36	96	132	27.2
March	6	39	45	12.3
April	0	112	112	—
Total	166	739	905	18.3
Station 3				
September	2	9	11	18.1
October	0	15	15	—
November	25	43	68	36.7
December	0	28	28	—
January	9	37	46	19.5
February	3	26	29	10.3
March	1	9	10	10.0
April	1	13	14	7.1
Total	41	180	221	18.5
Station 4				
September	2	11	13	15.3
October	9	4	13	69.0
November	1	7	8	12.5
December	16	9	25	64.0
January	11	14	25	60.0
February	1	0	1	100
March	18	16	34	53.0
April	0	7	7	—
Total	58	68	126	46.0

TABLE 10—(*Continued*)

Month	Number Living	Number Dead	Total	Per Cent
Station 5				
September	117	312	429	27.2
October	171	901	1,072	15.9
November	37	1,121	1,158	3.2
December	103	464	567	18.1
January	71	338	409	17.3
February	209	623	832	25.1
March	50	268	318	15.7
April	25	403	428	5.8
Total	783	4,430	5,213	15.0
Station 6				
September	2	5	7	28.5
October	9	52	61	14.7
November	24	22	46	52.1
December	8	17	25	32.0
January	21	45	66	31.8
February	27	32	59	45.7
March	8	6	14	57.1
April	0	16	16	—
Total	99	195	294	33.6
Station 7				
September	15	25	40	37.5
October	9	28	37	24.3
November	3	13	16	18.7
December	6	39	45	13.3
January	4	12	16	25.0
February	9	18	27	33.3
March	5	12	17	29.4
April	4	26	30	13.3
Total	55	173	228	24.1

higher temperatures, but continue to reproduce throughout the seasons at a lower rate. The reduced number of specimens living during the winter months includes those that have survived destruction by the sediment and other organisms.

The frequency distribution of the Foraminifera is one of the results of this survey that appears to be quite significant. More than 80 percent of the number of species are reworked Miocene-Pliocene fossils, yet they constitute less than 25 percent of the total assemblage. Knowledge of this fact has an important bearing in the interpretation of other sediments that formerly were believed to be largely the result of reworking, based on the finding of many single species representing a prior geologic age. Abundant fossil faunas occur in the Pliocene-Miocene strata of this area, so that diverse reworked species are easily accounted for. The precarious living conditions of the

TABLE 11—SUPPLEMENTARY DATA

Average pH for Period September 22, 1956 to April 18, 1957
(Based on 7 samples per station)

Station Number	pH
1	8.08
2	8.13
3	8.11
4	8.09
5	8.18
6	8.16
7	8.13

Average Salinity for Period September 22, 1956 to April 18, 1957
(Based on 36 samples per station)

Station Number	Salinity
1	33.52
2	33.78
3	33.72
4	33.06
5	33.01
6	33.16
7	33.02

Average Water Temperature for Period September 22, 1956 to April 18, 1957

Station Number	Water Temperature
1	16.0
2	15.7
3	16.1
4	15.9
5	16.4
6	16.2
7	15.6

Heavy Mineral Separations
(Acetylene tetrabromide)
(Samples collected April 12, 1957)

Station Number	Per cent of Heavy Minerals by Weight
1	4.5
2	15.9 (mostly ilmenite and magnetite)
3	1.3
4	.7
5	1.3
6	1.6
7	.9

Percentage of Carbonates
(All samples collected October 13, 1956)

Station Number	Per cent of Carbonates (soluble in dilute HCl)
1	24.6
2	2.7
2	2.7
3	1.0
4	0.7
5	5.3
6	1.4
7	1.6

intertidal habitat can explain the small number of species that can live in shoal waters. Note the tremendous increase of individuals at the protected stations (Table 6).

Another interesting observation is the relationship that occurs between the foraminiferal abundance and the median grain size of the beach sand. In almost every instance the number of specimens, based on a sample containing 100 grams of sediments, varied inversely with the median grain size of the sand. The greatest abundance of both the living and dead Foraminifera occurred in the sediment with a median diameter of less than 0.500 mm. Sand coarser than 0.500 mm. showed a marked decrease in the number of Foraminifera. This is the result of the settling rate of the Foraminifera tests, which, in most instances, are in the same grade range of the sand in which they are found. It appears that there is a winnowing of tests from the coarser sand.

The origin of the sand and the changes that it undergoes are based primarily on observations of the longshore current direction and the locations of stream channels entering the bay. It is apparent that the sand which replenishes the beaches of Santa Monica Bay comes from the northwest, and is initially supplied to the more northerly beaches through the flooding action of streams. Once the sand is deposited on the beach, the longshore currents carry large quantities to the southeast. The presence of a submarine canyon (Redondo) prevents a more continuous movement of the sand.

Results of this survey seem to indicate that no large variations in sand size are produced by tidal cycles, although it is important to realize that the alternating occurrence of neap and spring tides might logically be expected to cause such change. As other workers have mentioned, and as is apparent from this study, change in sand size is not correlated as much with the phase of the tide as with the amplitude of the waves. As there were only two moderately severe storms, accompanied by high waves, during the time of this survey, a definite correlation could be established only at these times. It may be concluded that variation in wave size will not only influence the amount of material transported, but also

the grain size as well, and therefore, ultimately the type and number of Foraminifera present.

The lack of fine-grained sediment may be due to its being in suspension in the intertidal zone and unable to come to permanent or semipermanent rest on the sea floor or beach; it will travel until rip currents or some other currents carry it to a place where its settling rate permits its deposition. It is felt that large quantities of fine-grained material are to be found beyond the intertidal zone, but that there would not be any large abundance of Foraminifera in this area.

One would expect that beach sands deposited during storm periods attended by strong winds and high surf would be markedly coarser than those deposited during calm weather. This was found to be the situation after the rather infrequent storms, but it did not hold true for sediments in general deposited during winter and spring months. The sands were coarser during these periods than in the fall season, however, and a trend could not definitely be established.

SYSTEMATIC PALEONTOLOGY

Family MILIOLIDAE d'Orbigny, 1839
Genus SCUTULORIS Loeblich & Tappan, 1953

SCUTULORIS REDONDOENSIS Reiter, n. sp.
Plate 79 figs. 1a-c

The test is small, short and broad. It is only slightly longer than broad in front view. Its periphery is rounded and the chambers are in quinqueloculine arrangement, increasing rapidly in size as added. The chambers are inflated. The sutures are distinct and slightly depressed. The wall is calcareous, imperforate, and thin. The surface is smooth with slight folding. The aperture is at the end of the chamber. It is semicircular with a broad flap.

This species is similar in appearance to *Scutuloris durandi* (Cushman & Wickenden) 1929, (U. S. Natl. Mus. Proc., no. 2780, v. 75, art. 9, p. 3, pl. 1, figs. 5a-d) from which it differs in the character of the aperature and the absence of pronounced costae.

Type Figure.—Plate 79, figures 1a-c, holotype, ×120: a-b; opposite sides, c; top view.

Locality.—Redondo Beach, Santa Monica Bay, California, in the intertidal zone.

Age.—Recent.

Holotype.—U.S.C. No. 4623.

Paratype.—U.S.C. No. 4624.

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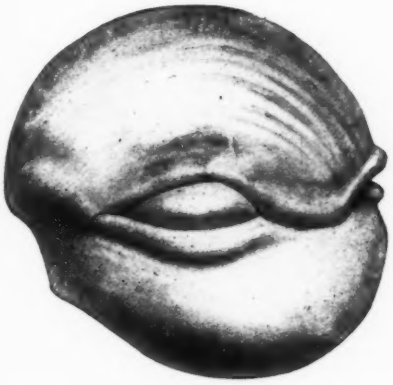
EXPLANATION OF PLATE 79

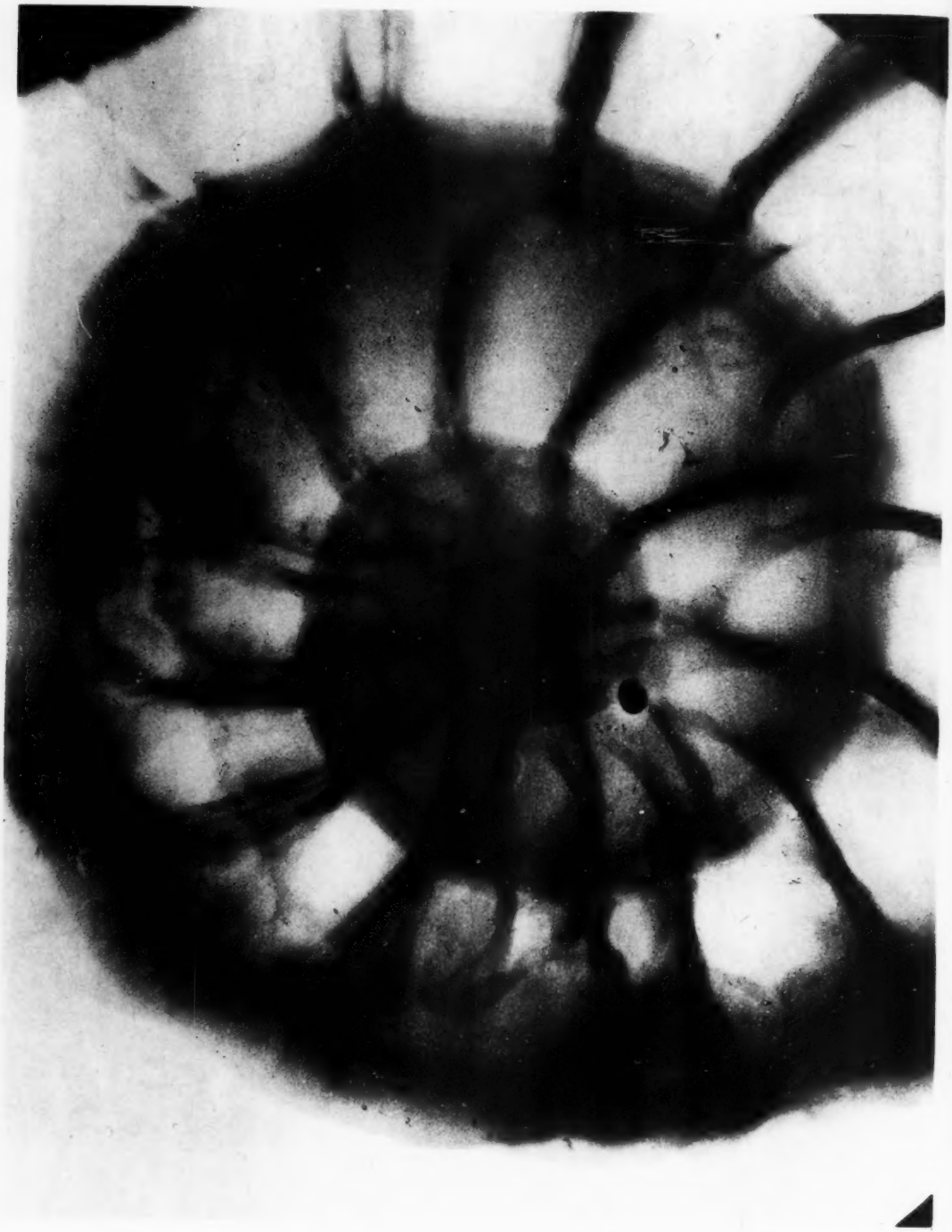
FIG. 1—*Scutuloris redondoensis* Reiter, n. sp. ×120. *a,b*, opposite sides; *c*, front view.



1A

1B

1C



JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 631–640, PLS. 80–82, 7 TEXT-FIGS., JULY 1959

X-RAY ABSORPTION TECHNIQUES APPLIED TO STATISTICAL STUDIES OF FORAMINIFERA POPULATIONS

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ABSTRACT—Projection microradiography (P.M.R.) and contact microradiography (C.M.R.) are applied to the elucidation and measurement of foraminifer microstructures. The Cosslett and Nixon projection x-ray microscope is used to produce microradiographs showing internal structures of the foraminifer *Operculina*. Details are given of a camera holding a maximum of twelve 5 cm. specimens (or a greater number of smaller ones) and using 35 mm. film.

Also, a C.M.R. technique using x-ray diffraction equipment and maximum resolution plates is shown to give microradiographs revealing internal structures for approximately 200 specimens per exposure. The image of each specimen is enlarged photomicrographically upon 35 mm. film strip. Some 14,000 measurements and counts of internal structures are taken from enlarged projected film strip images. The data are used in statistical studies of South Australian *Operculina* populations of Tertiary age (K. Hooper, 1958). Errors, due to penumbral blurring, emulsion grain size, resolution limits, photomicrography and projection are less than 5%; those of pencil line thickness are less than 10%. Total percentage errors vary inversely with size of the structure measured but are normally considerably less than maximum.

A comparative test with the conventional sectioning method (measuring proloculus diameter) shows errors of ±7%. It is claimed that microradiographic methods are nondestructive, speedy, more accurate than sectioning methods and suitable for quantitative foraminifer population studies.

GENERAL INTRODUCTION

IF POPULATION studies based upon biometrical and statistical techniques are to be encouraged, speedier, more accurate and nondestructive methods for measuring the internal structures of large numbers of foraminifera are needed. The following x-ray absorption techniques, tried out by the writer at the Cavendish Laboratory, Cambridge, and applied to the genus *Operculina* from the Tertiary rocks of South Australia, appear to fill that need.

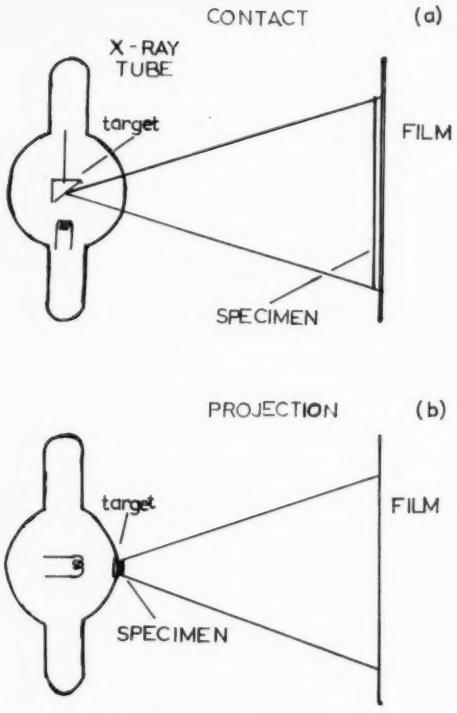
X-RAY ABSORPTION TECHNIQUES

Introduction.—Within two years of the discovery of x-rays by Roentgen in 1895, first attempts were made to produce magnified images. It was then thought impossible to focus x-rays and efforts were concentrated upon the optical magnification of the photographic image produced by x-rays. For example, Haycock and Neville of the Cavendish Laboratory, Cambridge, produced "microskiagrams" of sodium gold alloys. Gobi, 1913, Lamarque, 1936, Turchini, 1942 and Engstrom, 1946, have used soft (i.e. long wave length) x-rays to radiograph sections of plants and animals but the x-ray tubes used have been the continuously evacuated type involving elaborate and complicated apparatus. Barclay, 1951, and Mitchell, 1954, have used sealed-off tubes with higher inherent filtration and high tensions of 7–20k. v. (Combee, Houtman & Recourt, 1955). Since 1950, improvements in apparatus and materials have led to the application of x-rays for microscopic examination in many fields of scientific endeavour. In 1952, Schmidt used a contact method and Eastman 548-0 spectroscopic plates to produce some microradiographs of foraminifera.

Since then an even finer grained photographic emulsion has been evolved, and the

EXPLANATION OF PLATE 80

Projection microradiograph of an operculine, showing well-developed septa filaments, ×70.



TEXT-FIG. *1*—Diagram illustrating contact and projection X-ray microscopy.

maximum resolution plate has been produced. Recently (Hedley, 1957), contact microradiographs of some foraminifera have been produced using a commercially obtainable x-ray apparatus and maximum resolution plates.

Three methods of x-ray microscopy or microradiography are possible:

(1) *Reflection x-ray microscope.*—In this method, the x-rays are totally reflected from a mirror at a very small glancing angle. Then by a curved mirror system, the rays are focussed to achieve point-to-point imaging. This is a true microscope, using x-rays. The method has been developed by Kirkpatrick and Baez at Stanford (Nixon & Baez, 1956).

(2) *Contact microradiography* (*C.M.R.*)—The specimen is placed very close to the photographic plate or film, as shown in (Text-figure 1a), and the image is subsequently enlarged by optical means. A resolution of approximately 1 micron is claimed for this method. The limit is set by the grain size or granularity of the photographic emulsion used, so that very fine spectroscopic or maximum resolution emulsions must be employed. The limit of resolution is ultimately set by the optical microscope used to enlarge the image and this is in the order of 0.25 micron (Nixon & Baez, 1956).

(3) *Projection x-ray microscopy or projection microradiography* (*P.M.R.*).—In this method an electron beam impinges upon a target which emits characteristic x-radiation, (Text-fig. 1b). The specimen (object) is held in a holder which allows three-dimensional motion. Magnification change is obtained by varying the object-point source distance. The advantage of this method is that the image is an enlargement of the object and thus the grain size of film is less important than in C.M.R. This means that shorter exposure times are possible, because exposure time and grain size of film vary inversely. The method was developed by Cosslett and Nixon of the Cavendish Laboratory, Cambridge (Cosslett & Nixon, 1953).

In the present work both contact microradiography and projection microradiography are used.

PROJECTION MICRORADIOGRAPHY APPLIED TO THE GENUS *OPERCULINA*

The projection x-ray microscope used to produce the microradiographs of *Operculina* illustrated here was the Cosslett and Nixon tube, descriptions of which may be found in the literature (Cosslett & Nixon, 1953; Nixon & Baez, 1956). A diagrammatic representation of the projection x-ray microscope is shown in Text-figure 2a. Details of the object holder are seen in text-figure 2b. An electron gun produces an electron beam, which is focussed by a magnetic electron lens system to a point upon a target. The target, a thin metal foil, may be tungsten, gold, silver or other elements to reproduce the characteristic x-ray lines. In this investigation a nine micron copper foil target was most satisfactory. The electron beam was in vacuo, achieved by continuously pumping. The x-rays, at atmospheric pressure, were emitted from the target to form a cone with a 60 degrees solid angle on the outside of the thin foil window. The specimen was placed upon a thin piece of "sello-

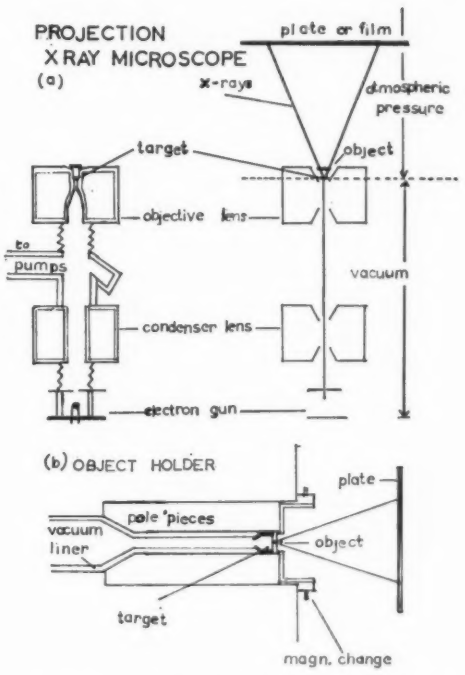
tape," which was held in the object holder. This holder allowed three-dimensional movement and thus change of magnification. The specimen was moved closer to the point source to obtain greater enlargement of the image, which was projected on to a photographic plate or film (Text-fig. 2).

In operation a test grid was used as specimen; its image on a fluorescent screen of ¼-inch plate glass (coated on the underside with aquadag), was viewed through a lens and the controls manipulated to focus the electrons to a point source, giving a sharp grid image. The test grid was then removed and a specimen operculine placed in the object holder. An improvised camera, consisting of a cardboard box with a hole cut in the bottom, was loaded with photographic plate or film. It was then placed in position above the object holder; specimen to plate distance was arranged by a ½-inch brass tube spacer, which also protected the operator from stray radiation. An exposure was made and the plate or film developed.

Plate 80 is a print from a microradiograph produced by this method. The exposure was approximately two minutes, the distance 4 cms. using Ilford special lantern plate, contrasty grade. The voltage was 28 kv., the current 10 microamps.

Inspection of the results showed that P.M.R. was able to give good microradiographs of *Operculina* particularly in horizontal (median) view. Later exposures made at various angles of tilt showed that useful information can be obtained up to 40 degrees of tilt, but further obliquity produced an image confused by overlapping detail. The edges of septa, marginal cord and proloculus were not sharply defined, and the density tended to grade outwards from the center of the wall. This is a feature common to all radiographs of structures of variable thickness relative to the path of the x-rays. It results in a gradation effect and may lead to serious errors in measurement, especially if the photographic work is substandard.

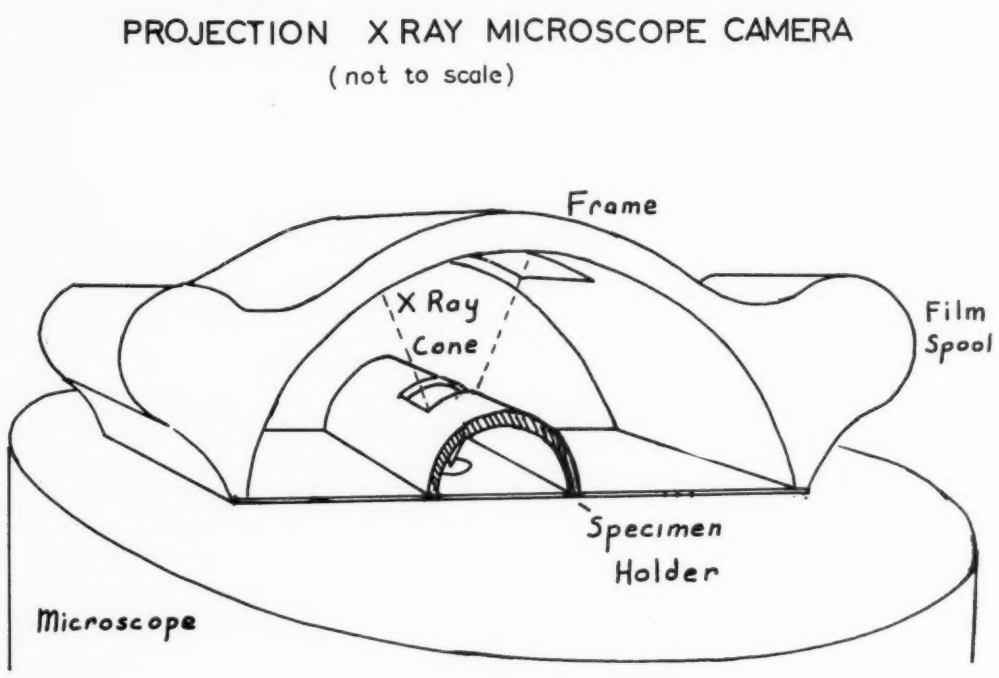
Plate 80 is especially interesting as it is a plan (horizontal, median) view showing considerable development of septal filaments. This information would not be obtainable from a conventional median section; an axial (vertical) section would be necessary.



TEXT-FIG. 2—Diagram illustrating projection X-ray microscopy (after Nixon).

For the degree of enlargement required here, maximum resolution plates with their long exposure times are not essential, because some degree of magnification is given by the projection x-ray microscope itself. This suggested the possibility of using film. Subsequently Pan.F. film was successfully used, giving photographically "soft," but otherwise good microradiographs. The chief disadvantage of P.M.R. was the small number of specimens that could be handled per exposure. It was this fact that ultimately led to its rejection for the rapid investigation of the large numbers of specimens comprising fossil population samples. However, this view does not preclude the possibility that P.M.R. might finally have more future usefulness than C.M.R., even for population studies, because the greater depth of focus obtainable is important in quantitative stereomicroradiography.

A suggested method for increasing the number of specimens per exposure using P.M.R. follows. A brass camera built to the



TEXT-FIG. 3

semicircular pattern is shown in Text-figure 3. The camera in which a series of detachable slotted brass arcs act as object holders, carries a 35 mm. film strip.

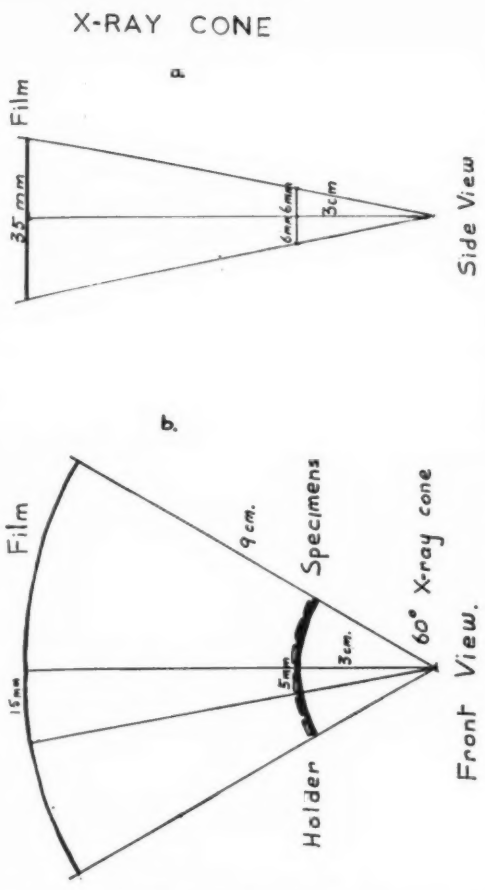
The arc shaped holders are fitted to calculated point source to object distances. The fossils are placed upon adhesive "sellotape" fixed over a cut out area (the window of the holder), so that they are each normal to the x-rays which emerge from the point source to form a 60 degree solid angle cone. This radial arrangement reduces distortion of the image from parallax; which because the fossil has an average thickness of approx. 0.5 mm. could be serious at short distances from the normal ray (see Text-fig. 4b). In the width direction the holder is not curved (see text-fig. 4a), and it has been calculated that in order to avoid more than $2\frac{1}{2}\%$ distortion of image due to specimen thickness, a maximum distance of 6 mm. from the normal is required. Thus two rows of six 5 mm. diameter specimens could be accommodated at a holder distance 3mm. from the source (i.e. radius of curvative 3 mm.) giving a magnification approx. 3 times with the film 9 cms. from the source and an exposure time approximately 100 minutes. By increasing the radius of curvature of the holder more specimens could be accommodated, but magnification would be lower. However, exposure time would not be affected.

In view of the time necessary to build the camera described above, the comparatively small number of specimens the camera could hold and the long time involved in exposing many hundreds of specimens, an investigation of contact microradiography was commenced.

CONTACT MICRORADIOGRAPHY OF *OPERCULINA*

The ordinary x-ray diffraction equipment of the University of Cambridge, Department of Mineralogy, was used; two simple brass cylindrical cameras were made to hold the specimens and the maximum resolution plates.

The apparatus consisted of a continuously evacuated demountable x-ray tube, a straight line tungsten filament focussed by bias, a copper target (water-cooled), and a

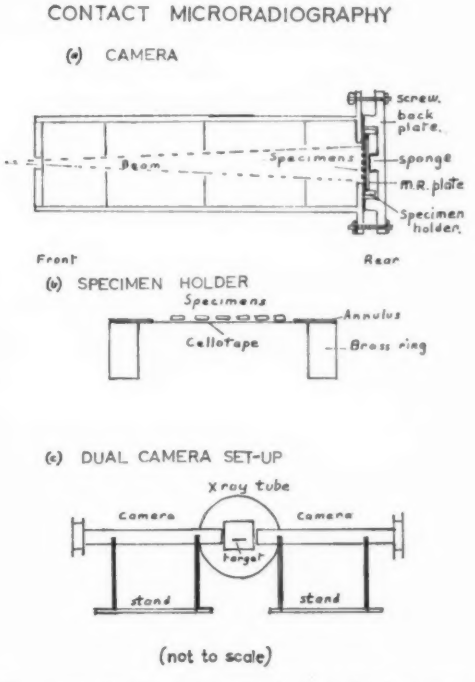


TEXT-FIG. 4—Diagram showing arrangement of arc-shaped holders.

beryllium window, diameter 5 mm. The 1 mm. sq. spot was line focussed; the take-off angle of x-rays was 5 degrees and the distance from spot to window, 25 mm. It was operated at 30 k.v., 18 m.a.

To hold the specimen and plates, two cameras were cut from 2 inch diameter, one-eighth inch thick walled brass tubing so that the total plate-spot distance was 40 cms (Text-fig. 5a). A series of baffle rings was inserted in the tubes to give an image diameter of 4 cms. and to prevent x-rays reflected from the brass tube walls from reaching the photographic plate. A thin piece of black paper in the aperture prevented light intrusion. The specimen holder comprised an adhesive "sellotape" sheet fixed to a cardboard annulus of interior diameter 4 cm., exterior diameter 6 cms. This was fixed to a brass ring of depth 0.5 cm., diameter 6 cms., with the adhesive surface upwards as shown in the diagram (Text-fig. 5b). The foraminifera were placed upon the adhesive surface of the "sellotape" in a plane spiral. The holder was held in position by a brass plate screwed on the rear of the camera tube, as shown in text-figure 5a.

The procedure followed was to take previously numbered specimens from the population sample according to the sequence given for random numbers in Statistical Tables for Biological, Agricultural and Medical Research (Fisher & Yates). Each specimen was measured for thickness at the center by micrometer screw gauge. A description of its external features was made and in the case of strongly umboed or lenticular forms, which tended to lie at an oblique angle, the central ornament was removed to ensure a horizontal position and a clearer microradiograph. The specimen was then pressed upon the adhesive surface of the



TEXT-FIG. 5—Diagrams illustrating single camera, specimen holder, and dual camera set-ups.

"sellotape." The specimens were carefully checked for horizontality.

The position of the cameras with respect to the x-ray beam was arranged by resting them upon stands (Text-fig. 5c). Only the central portion of the beam was utilized so that at a distance of 40 cm. and an image diameter of 4 cms., for all practical purposes the x-rays may be regarded as parallel. The cameras were loaded under "safe light" conditions, Kodak Maximum Resolution Plate being cut to size and placed (emulsion to nonadhesive side of the "sellotape") in the specimen holder. The holder was then placed in position with the specimen-bearing (adhesive) surface forwards. The brass back plate was screwed into position and the cameras were placed upon their stands with protective lead linings in position. The x-ray beam was switched on.

Exposure times were 5 hours at 18 m.a. 30 k.v. for thin specimens and 7 hours at 18 m.a. 30 k.v. for thick specimens. The long exposure times necessary using this method were compensated for by the large number (200 max.) of specimens that could be handled per exposure per camera; in addition two cameras could be operated from one x-ray tube concurrently. Development was by Kodak No. 58 Developer for 3 minutes. The processed plate (the negative) was not suitable for direct enlargement because of density variations from image to image over the plate area. This is illustrated in plate 81—a direct enlargement of a contact microradiograph plate. It was necessary to photocopy the image of each specimen separately.

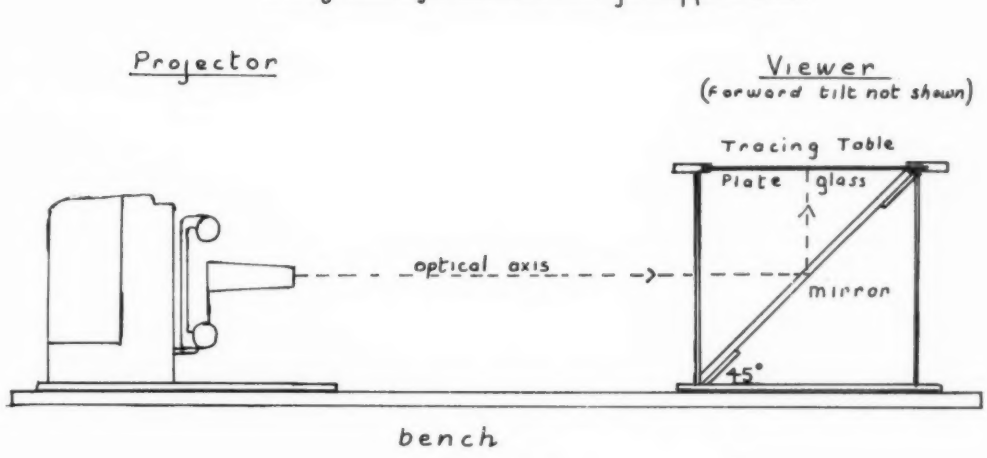
Photomicrography of contact microradiographs.—Ordinary microscopes with the usual ocular-objective combinations were not suitable for photomicrography of the individual specimen images because the small diameter of the microscope tube gives a small field of view, and variation in size of *Operculina* is large. Thus, frequently it was not possible to photograph the entire specimen in one frame. The following apparatus was constructed to avoid the difficulty.

A heavy metal bracketpiece was modified to form a stand for a 35 mm. Leica camera (lens removed) with a Leica reflex bellows attachment. A series of holes drilled in the stand allowed the vertical position of the camera and attachment and of the stage to be varied by adjusting a screw. The reflex attachment was modified to take interchangeable lenses, checked for maximum flatness of field to reduce distortion of the image to the minimum. The contact microradiograph was placed emulsion upwards upon the stage over a previously drilled 1 cm. diameter hole in line vertically with the lens. To accommodate the full range of size variation of *Operculina* adjustments were made to lens, bellows and camera height to give optimum magnification of individual specimen image. Two lenses and two positions of the camera relative to the stage, (i.e. film to microradiograph plate distance), were necessary. Thus two series of exposures were required, the apparatus being focussed upon a graticule of known size at the beginning of each film roll or when the magnification was changed. Later this graticule frame was used to obtain the 100 times total enlargement by projection.

METHODS OF MAKING MEASUREMENTS

Two methods of measurement making are described below.

(1) *The use of distortionless photographic paper.*—For microradiographic work, a moderately well-equipped photographic department is essential. It therefore seemed reasonable to the author to make photographic enlargements (prints) from the individual microradiographs with a view to making direct measurements of selected characters on these prints, using a ruler and a protractor. Bromide and other photographic printing papers have up to 3% dimensional instability, the amount of distortion varying in different directions. However, Kodak waterproof paper with less than ½% dimensional instability is well within the accuracy limits. Its advantages are: (a) apparatus for measurement making is minimal, (b) working under normal light conditions reduces eye strain, (c) measurements can be made almost any time and place, (d) the paper dries quickly. The disadvantages are: (a) high cost of the paper—about 1½ times that of bromide paper, (b) only a limited amount of enlargement is practicable or even possible from the 35 mm. negative, depending upon the enlarging apparatus available.



TEXT-FIG. 6

(2) *Projection.*—The apparatus comprised; (a) a Leitz Prado 150 watt projector with a Hektor f-8.5 cm. lens, (b) a portable viewer, (c) a tape recorder, (d) translucent graph paper lined in mm., (e) transparent ruler and protractor.

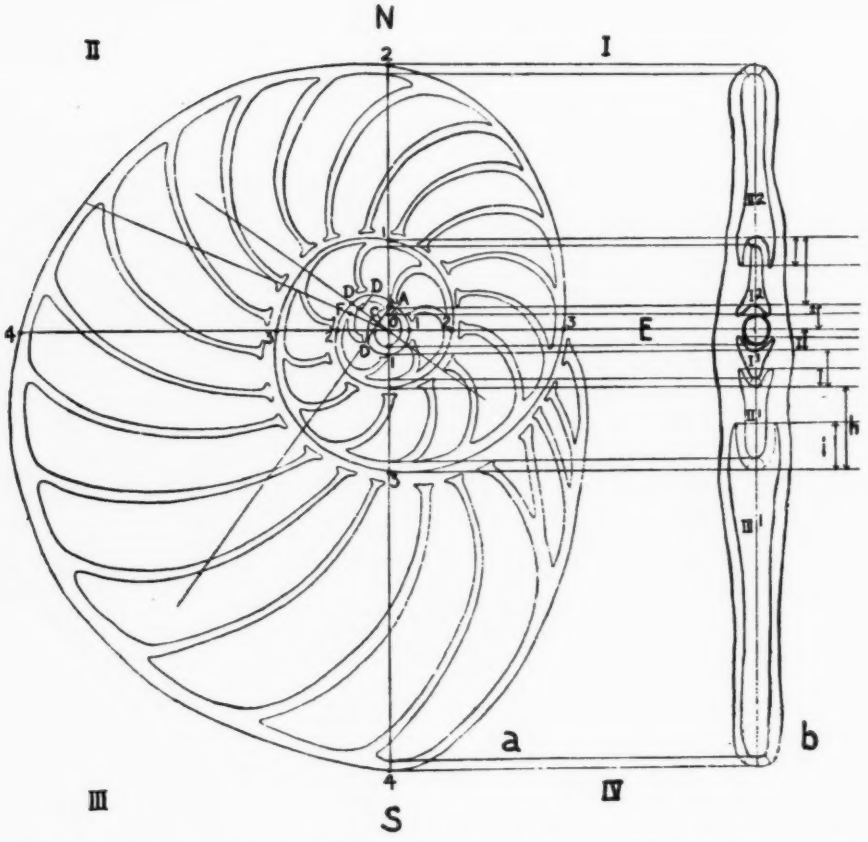
The viewer was essentially a collapsible wooden "box' with one side removed and a lid of good quality one-eighth inch plate glass 32 cm. square, set in a wooden frame (Text-fig. 6). A good quality plate glass mirror was set in the "box" at an angle of 45 degrees. The viewer was placed upon a bench and tilted forward, so that the glass lid formed a tracing table, with the surface inclined slightly towards the operator for convenience of drawing. Translucent graph paper was placed upon the glass surface and made fast with "sellotape."

(a) *Setting up of the apparatus.*—The projector was set up facing the open end of the viewer with its axis parallel to the bench and at right angles to the viewer. The graticule (first frame of the film strip) was projected, the projector to viewer distance being adjusted to give 100 times total enlargement of the graticule upon the tracing paper. The projector was then securely fixed in position.

A series of comparative measurements over sections of the projected graticule image was made. It was found that the distortion between the center and the perimeter was less than 2%. Because the graticule is photographed with the photomicrographic apparatus described, the total distortion (optical and photographic), from apparatus, projector and viewer, is included in this figure.

(b) *Measurements.*—The image of an operculine was projected upon the graph tracing paper, and the lines of structures to be measured were strengthened, with a sharp H.B. pencil. Eyestrain was reduced by inserting a green filter in the projector. Measurements were made with a ruler and protractor in the same sequence as their headings appeared upon the raw data sheets and were called in the same sequence into the tape recorder. Later, the tape was played back and the measurements were written onto the raw data sheets. It was estimated that the time taken to make the 14,000 measurements recorded was reduced 50% by using the tape recorder in this way. The specimen was oriented as in Text-figure 7. The measurements taken were as follows:

(1) Test diameter (a) North-South direction. (b) East-West direction.
(2) Number of whorls.
(3) Angle OAB.
(4) Angle DOF.
(5) Surface of the median section of first three chambers. (a) Proloculus. (b) Second chamber. (c) Third chamber.
(6) Proloculus diameters. (a) Internal North-South. (b) Internal East-West. (c) Ex-



TEXT-FIG. 7—Diagram illustrating measurements made on operculine specimen (after Bannik).

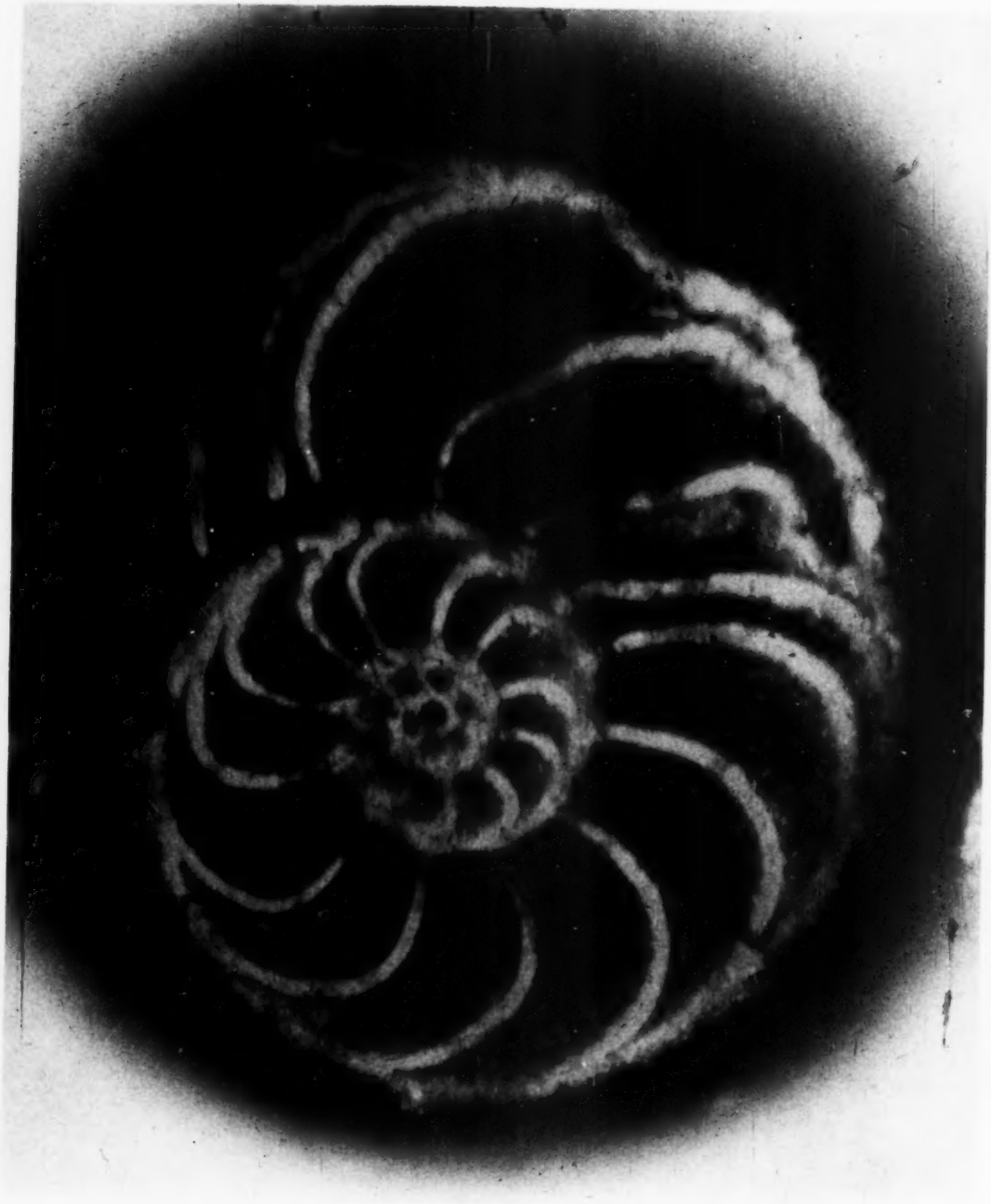
ternal North-South. (d) External East-West.
(7) Second chamber, lengths. (a) AB. (b) CD. (c) CD_1.
(8) Whorl heights for 1st, 2nd, 3rd and 4th whorls at each quarter whorl.
(9) Number of chambers to fixed distances measured around the whorl (excluding proloculus).
(10) Whorl heights to fixed distances around the whorls. (a) to 3 mm. (b) to 6 mm. (c) to 12 mm.
(11) The measurements (a) N_2S_2. (b) N_1N_2
(12) Diameter of the test at N_2S_4.
(13) Maximum septal filament length per whorl, (a) first whorl, (b) second whorl, (c) third whorl.

(c) *Discussion of accuracy.* (1) *Penumbral blurring.*—Nixon has discussed the limitation imposed upon contact microradiography by penumbral unsharpness (Nixon & Baez, 1956). This is given by the formula,

$$\frac{f}{p}=\frac{d}{t}$$

EXPLANATION OF PLATE 81

Direct enlargement of a microradiograph plate, showing density variation between specimens, ×10.



where,

f is focal spot size
p is penumbral blurring
d is distance of specimen from spot
t is thickness of specimen

$$\therefore p = \frac{ft}{d}$$

Substituting the values used in this work, we have,

$$p = \frac{1 \times 0.5 \text{ mm.}}{400}$$

$$= \frac{1}{800} \text{ mm.}$$

assuming average thickness of specimen to be 0.5 mm.—a rather high estimate.

Penumbral blurring = 1.25 micron.

Thus we cannot have complete depth sharpness in the C.M.R. method. This is important in stereomicroradiography (K. Hooper, 1958).

(2) *Limitation due to grain size and granularity of the photographic emulsion.*—The properties of fine grained photographic emulsions used in microradiography, are stated by Engstrom & Lindstrom (1951). In the present work, Kodak Maximum Resolution Plates were used, for which the makers claim a resolving power of 1000 lines per mm. The contraction or elongation of the emulsion was less than 0.1%.

(3) *Resolution.*—In discussing the resolution obtainable using C.M.R., Nixon has illustrated a 3 micron triangular metal grid, (1) contact microradiographed, (2) photomicrographed, for comparison. The triangular bars of the grid are thinner in the former image than the latter. This is due to the excessive x-ray penetration at the edges of the bar. Thus it is necessary to distinguish between the resolution limit and the contrast. Therefore, correct exposure and development of the photographic plates for the structures of particular interest, is important. From these considerations it is apparent that the resolution limit is in the order of 1.25 microns for this work.

(4) *The effect of the shape of the internal structures.*—From Nixon's comparative images measurement of curved structures, such as the proloculus wall, might be seriously in error if the wall is very thin or the radius of curvature very small. It has been calculated that as the thinnest wall in the South Australian operculines is 10 microns, and it has a radius of curvature 30 microns; then, the loss of resolution of the outer edge is less than 0.5 micron, or 5% of wall thickness. This is an extreme case, for the vast majority of specimens it must be considerably less. This could be a serious disadvantage for measurement of marginal and septal canals and pores in *Operculina* and other camerinid genera.

(5) *Errors due to photomicrography, projector and viewer.*—These have already been discussed above and estimated at 2%. However, this figure does not include pencil and ruler errors.

(6) *Pencil error.*—The thickness of a fine line upon tracing graph paper, drawn by a sharp H.B. pencil was estimated as 0.2 mm. Comparing this to the minimum proloculus wall thickness, 10 microns, which enlarged 100 times became 1 mm. on the image we have,

$$\frac{0.2 \text{ mm.}}{100} = \frac{1}{5} = 20\%.$$

Thus, the maximum possible error for the extreme case is 20% of the wall thickness. However, this structure has not been used as a character. In the case of the minimum proloculus radius, a character that has been used, the largest error is 10% of the radius. This is the greatest error possible in this work and it occurs in this extreme case. All other errors must be less than it.

(7) *Comparative test with the sectioning method.*—It seemed advisable to compare

EXPLANATION OF PLATE 82

Contact microradiograph of an operculine, ×40.

measurements obtained by contact microradiography with those of the conventional sectioning methods. Ideally, all the specimens microradiographed, or a random sample of them, should be sectioned and measurements compared; to have done this would have destroyed the specimens which were required for further study. Therefore one large, one medium and one small specimen were sectioned giving an approximate estimate of comparative measurements.

For a sectioned specimen the maximum of a series of proloculus diameter measurements was taken as the true proloculus diameter. This was compared to the proloculus diameter of the specimen as revealed by C.M.R. Results indicated an average compartive error of approximately $\pm 7\%$.

(8) *Conclusion.*—Because in both methods the measurement was finally made by ruler against a pencil line, and this has been shown to introduce the grossest error of all, it may be argued that the preceding attention to finer accuracy was unnecessary. However, the % error due to the thickness of the pencil line depends upon the degree of enlargement of the image and the size of the structure measured. It has been shown above that the 10% error is the highest possible for the specimens studied here, and is not normal. Contact microradiography appears to offer a more accurate method of measuring internal structures than usual sectioning techniques.

Measurements and counts obtained from microradiographs have been applied to statistical studies of four South Australian *Operculina* populations of Tertiary age (K. Hooper, 1958). It is hoped to publish these as a separate paper in the near future.

ACKNOWLEDGMENTS

Thanks are due to the following: Dr. Martin Glaessner, University of Adelaide, for the author's introduction to the genus *Operculina;* Dr. V. E. Cosslett, Cavendish Laboratory, Cambridge, for x-ray facilities there; and Dr. J. V. P. Long whose laboratory the author shared; the University of London for permission to publish this paper which is part of a thesis of the University.

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MIOCENE (BURDIGALIAN) FORAMINIFERA FROM KATHIAWAR, WESTERN INDIA

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ABSTRACT—Sixty foraminiferal species and varieties are recorded from the Miocene (Burdigalian) beds of Kathiawar, Western India: These include one new species—*Palmerinella raoi*. The paleoecology of the beds is discussed. The foraminiferal evidence suggests a gradual increase in the depth of the oceanic basin following the initial marine transgression in the area. The fauna shows affinity with the Indo-Pacific forms, although a certain admixture with the "European" species is noticeable.

INTRODUCTION

THERE has been an increasing need in recent years for the age-determination and correlation of rather widely separated Tertiary outcrops in the Indo-Pacific region. This has so far been done mainly on the basis of larger Foraminifera and mollusks (*vide* Eames, 1950, 1953; Glaessner, 1943, 1951; Vlerk, 1955; Rao *et al.*, 1957). Very little, however, is known concerning the occurrence and distribution of Tertiary smaller Foraminifera of western India. Recently, Bhatia & Mandwal described a rich foraminiferal fauna consisting of 26 species and varieties from the Agate-conglomerates (Burdigalian) of the Surat-Broach area. The present paper gives a systematic account of the smaller Foraminifera from the Miocene (Burdigalian) beds of Kathiawar, western India. The rich foraminiferal fauna which forms the basis of the present study was obtained from samples collected by Mohan during the field seasons 1952–54 from six different localities spread along the coastal areas of Kathiawar.

The authors take this opportunity to express their gratitude to Prof. S. R. N. Rao, Department of Geology, Lucknow University, for his critical reading of the manuscript and also for many helpful suggestions which he always willingly provided; and to the Director, Geological Survey of India, Calcutta, for library privileges.

PREVIOUS WORK

Perhaps the earliest reference to Foraminifera from Kathiawar is by Carter (1853, 1861) who described *Orbiculina malabarica* (Carter) from the middle Tertiary limestone near Porbander. This species has recently been referred to the genus *Taberina* Keizer (*vide* Henson, 1950). Fedden (1884) recorded *Conulites* or *Pattelina* from the shaly marls, 1½ miles N. 34° E. of Bhogat village. This record, however, has been discredited by Mohan & Chatterji (1956, p. 349) who consider it to be a *Lepidocyclina*.

Chatterji *et al.* (1953, pp. 13–14) recorded for the first time from India, the subgenus *Trybliolepidina* from Bhogat and Verawal. Other forms recorded by them were: *Taberina* (*Orbiculina* auctorum) *malabarica* (Carter), *Austrotrillina howchini* (Schlumberger), *Gypsina globulus* Reuss, *Miogypsina* sp., and *Miogypsinoides* sp.

Singh (1953) recorded the presence of *Miogypsina* sp. and *Miogypsinoides* sp. from the Miocene grits and conglomerates exposed near Gogha.

Mohan (1954) studied the Miogypsinidae from Kathiawar and recorded the following species: *Miogypsina* (*Miogypsina*) *irregularis* (Michelotti), *M.* (*Lepidosemicyclina*) *polymorpha* Rutten, and *M.* (*M.*) n. spp.

Chatterji (1955) recorded the following Foraminifera from the Gaj beds (Miocene) of various localities in Kathiawar: *Taberina malabarica* (Carter), *Austrotrillina howchini* (Schlumberger), *Lepidocyclina* (*Nephrolepidina*) *borneensis* (Provale), *L.* (*N.*) *martini* (Schlumberger), *L.* (*N.*) *morgani* (Lemoine and Douvillé), *L.* (*Trybliolepidina*) n. spp., *Gypsina globulus* Reuss, *Archaias angulatus* (Fichtell & Moll), *Sorites marginalis* (La-

marck), *Operculina bartschi* Cushman, *O. granulosa* (Leymerie), *O. malabarica* Jacob & Sastri and *Borelis* cf. *B. melo*.

Recently, Mohan & Chatterji (1956) described the stratigraphy of the Miocene beds of Kathiawar, and on the basis of the distribution of larger Foraminifera, recognized three distinct horizons as follows (in descending order):

3—"*Orbiculina*" limestones; marly limestones of Bhogat and Verawal, containing *Austrotrillina howchini* (Schlumberger), *Taberina malabarica* (Carter), *Lepidocyclina* (*Nephrolepidina*) *borneensis* (Provale), *L.* (*N.*) *martini* (Schlumberger) n. var., *L.* (*N.*) *morgani* (Lemoine and Douvillé), *L.* (*Trybliolepidina*) n. spp., and *Miogypsina* (*Lepidosemicyclina*) *polymorpha* (Rutten).

2—Visawara limestone; yellow to dark yellow compact limestones containing *Austrotrillina howchini* (Schlumberger), *Lepidocyclina* (*Nephrolepidina*) *borneensis* (Provale), *Miogypsina* (*Miogypsina*) *irregularis* (Michelotti) and *Miogypsina* (*Lepidosemicyclina*) *thecidaeformia* Rutten; agate conglomerates of Bhavanagar, containing *Miogypsina* cf. *antillea*.

1—Bhatia limestone (*Miogypsina* beds); dark yellow to brown, hard, compact, lateritic limestone containing *Miogypsina* (*Miogypsina*) *irregularis* (Michelotti) and *Miogypsina* (*Miogypsina*) n. sp.

They considered unit 3 to be of Upper Burdigalian age and units 2 and 1 to be of Lower Burdigalian age—corresponding to stage f1–f2 of the letter classification of Indonesia.

GENERAL GEOLOGY AND PROVENANCE OF MATERIAL

The Miocene beds of Kathiawar occur as small isolated patches along the coast from near Gogha in the southeast to Okha Mandal in the northwest. These have a gentle dip towards the coast and lie unconformably either over laterite or on the denuded surface of basaltic trap. Lithologically they consist mainly of yellow marls, limestones and sands. The aggregate thickness of the Miocene beds is estimated to be several hundred feet. The stratigraphy of these beds has already been described in detail by Fedden (1884) and Mohan & Chatterji (1956).

The samples for the present study were collected from the localities mentioned below; the symbols are those of Mohan & Chatterji (1956, Text-figs. 1 and 3):

"*Orbiculina*" Limestone

Locality Vwl (Verawal area)—1½ miles west of Khorasa village (21° 03′ N, 70° 20′ E)

Locality H (Bhogat area)—1½ miles N. 34° E. of Bhogat village (21° 59′ N, 69° 14′ E)

Visawara Limestone

Locality Vf (Visawara area)—near Visawara village (21° 47′ N, 69° 27′ E)

Bhatia Limestone

Locality F (Bhogat area)—from a newly dug well, from beds underlying the "*Orbiculina*" limestone, about one-half mile east of Loc. H

Locality D (Bhatia area)—about one-half mile east of Bhatia railway station (22° 06′, 69° 16′ E)

Location B (Bhatia area)—about 1½ furlongs north of Bhatia railway station.

PALEOECOLOGY OF THE KATHIAWAR MIOCENE

Reconstruction of ecological conditions necessitates the investigation of the depositional environments. The Miocene beds of Kathiawar (as is true of other marine coastal deposits in India) were formed as a result of marine transgression. The deposits thus formed are generally characterized by 1) shallow-water depositional environment, 2) coarser nature of the sediments, 3) moderate thickness of the beds, 4) occurrence as thin strips near the existing coast line, and 5) gentle dip towards the coast.

Marine transgressions commence with a gradual advance of shallow epeiric seas over slowly submerging land. Such transgressions bring with them the littoral environment, which is subsequently replaced by the comparatively deeper, epineritic environment. The neritic environment extends from the low-tide line to a depth of 600 ft. (100 fathoms) (Krumbein & Sloss, 1951, p. 209) and is generally subdivided into the epineritic environment, with water depth less than 120 ft. (20 fathoms), and the infraneritic en-

vironment, with water depth from 120 to 600 ft. (20–100 fathoms) (Scott, 1940).

Conflicting views have been expressed concerning the ecological factor or factors which control the distribution of benthonic Foraminifera in the neritic environment. According to Glaessner (1948, p. 190), " . . . the most important factor controlling the distribution of living Foraminifera is not depth but temperature." According to Said (1951, p. 12), however, "The importance of temperature seems to be confined to its control of the general and gross distribution of foraminifera in the seas of the world and its effects in retarding growth, but temperature does not seem to have much effect on the distribution of species within small, enclosed basins." He further stated that "The most important single factor that determines the appearance and abundance of bethonic foraminifera seems to be the oceanographic condition of the basin under consideration." Krumbein & Sloss (1951, p. 209) stated that "The wide range of conditions in the neritic environment is largely dependent upon water depth and supply of clastic material."

As already pointed out, the Miocene beds of Kathiawar were deposited in a shallow transgressive sea. The vertical changes in the lithology, coupled with the changes in the foraminiferal fauna from the lower to the upper part of the Miocene beds, indicate a gradual increase in the depth of the oceanic basin following the initial marine transgression. Using Scott's terminology, it is here suggested that the basal Miocene beds (unit 1, Bhatia limestone) were deposited in a near-shore, epineritic environment, while the upper beds (units 2 and 3, Visawara and "*Orbiculina*" limestone) were deposited in an off-shore, infraneritic depositional environment. From the evidence available, it is difficult to say whether any other factor like climate, position of shore, etc., had any direct influence on the distribution of benthonic life. These conclusions are substantiated by the nature of the sediments, and the presence of thick-shelled oysters and other mollusks.

Unit 1 (*Bhatia limestone*).—Samples from this horizon (*viz.*, B, D, and F) are characterized by the abundance of *Streblus annectens* and *Elphidium indicum* (see Distribution Chart). Both these species are characteristic Indo-Pacific forms and a survey of the literature concerning their ecological data shows that they occur frequently in shallow waters, particularly in the coral-reef regions. The almost exclusive occurrence of these species in the Bhatia limestone, therefore, suggests that these beds were laid down in warm shallow waters, possibly at depths less than 20 fathoms. These conclusions are in harmony with the views expressed by Marks (1951, p. 33) concerning the paleoecology of certain Miocene beds of the Vienna Basin that "The almost exclusive occurrence of *Elphidium* and *Rotalia* clearly indicates a shallow water depositional environment."

This unit is further characterized by the abundance of *Miogypsina* spp. Little is known concerning the bathymetric range of the genus, as it does not survive to the present day. However, since *Miogypsina* spp. occur abundantly with *S. annectens* and *E. indicum*, it may reasonably be inferred that they all occupied the same ecological niche, i.e., a shallow-water depositional environment. This is also in accordance with the views of Galloway (1933) and Vaughan (1933) that the family Orbitoididae (including Miogypsinae) as a whole occurs in warm, shallow-water deposits. Similarly Drooger (1955, p. 33) while discussing the paleoecology of the Aquitanian-Burdigalian beds of southwestern France, concluded that " . . . the Miogypsinae lived in near-shore, turbulent water of the neritic zone, though not in that part with considerable surf action."

Units 2 and 3 (*Visawara and* "Orbiculina" *limestones*).—Ecological conditions during the deposition of these two units appear to have been different from those that occurred during the deposition of the underlying unit (Bhatia limestone). The rich and varied foraminiferal assemblage from these beds indicates that they were deposited in an offshore, infraneritic depositional environment, at depths between 20 and 100 fathoms.

In the Visawara limestone (sample Vf) the total number of species increases to nine as compared to three in sample B from the Bhatia limestone. The predominant species in this zone are *Elphidium indicum*, *Austrotrillina howchini*, *Discorbis bractifera* and

TABLE 1—DISTRIBUTION OF BURDIGALIAN FORAMINIFERA IN KATHIAWAR, WESTERN INDIA

Species \ Localities	Bhatia Limestone			Visawara Limestone	"*Orbiculina*" Limestone	
	Loc. B	Loc. D	Loc. F	Loc. Vf.	Loc. H	Loc. Vwl
Involutina sp.						F
Glomospira sp.						R
Textularia agglutinans d'Orbigny				R	A	A
Textularia gramen d'Orbigny			R	R	A	A
Spiroplectammina sp.						R
Clavulina angularis d'Orbigny					R	R
Clavulina pacifica Cushman			R		A	A
Clavulina? aff. *C. serventiy* Chapman & Parr				R	F	R
Quinqueloculina aff. *Q. adelaidensis* Chapman & Parr var. *minuta* Keizer						R
Quinqueloculina anguina (Terquem) var. *arenata* Said						F
Quinqueloculina lamarckiana d'Orbigny						F
Quinqueloculina laevigata d'Orbigny					R	R
Quinqueloculina seminulum (Linnaeus)	R	F			A	A
Quinqueloculina venusta Karrer					R	
Quinqueloculina vermicularis Karrer					R	
Quinqueloculina sp.						R
Sigmoilina tenuis (Czjzek)						R
Spiroloculina excavata d'Orbigny						F
Spiroloculina obscura Cushman & Todd					R	
Spiroloculina tricosta Cushman & Todd					R	
Spiroloculina sp. A					R	R
Spiroloculina sp. B		R				
Spiroloculina sp. C			R			
Triloculina garretti Howe						R
Triloculina aff. *T. rupertiana* (Brady)					R	R
Triloculina tricarinata d'Orbigny					R	R
Pyrgo bulloides (d'Orbigny					R	
Pyrgo sp.						R
Lagena cf. *L. striata* (d'Orbigny)						R
Glandulina laevigata d'Orbigny						R
Globulina gibba d'Orbigny						F
Nonion boueanum (d'Orbigny)						F
Elphidium indicum Cushman	F	F	F	A	A	A
Elphidium subinflatum Cushman					R	
Reussella spinulosa (Reuss)					R	R
Reussella spinulosa (Reuss) var. *laevigata* Cushman					R	R
Reussella sp.						R
Bolivina marginoserrata LeRoy						R
Loxostomum sp.						R
Geminaricta virgata (Cushman) var. *costifera* Cushman						F
Discorbis aff. *D. australis* Parr						R
Discorbis bractifera Le Calvez			R	F	F	
Discorbis globularis (d'Orbigny) var. *bradyi* Cushman					R	R
Discorbis mira Cushman						R
Valvulineria californica Cushman					R	
Rotalia aff. *R. sumatrana* LeRoy					R	R
Streblus annectens (Parker & Jones)	A	A	A	R	R	R
Streblus sp.					R	R
Eponides sp.					R	R
Asterigerina dollfussi Cushman					R	A
Asterigerina planorbis d'Orbigny			R	R	R	A
Globigerinoides triloba (Reuss)						F
Globorotalia cf. *G. menardii* (d'Orbigny)						R
Anomalina grosserugosa (Gümbel)					F	
Palmerinella raoi, n. sp.						F
Anomalinella rostrata (Brady)		R		R	A	R
Cibicides lobatulus (Walker & Jacob)			R	R	F	F
Cibicides tapanoeliensis LeRoy						A
Cibicides telisaensis LeRoy						F
Planorbulina mediterranensis d'Orbigny)					R	R

R = Rare = 1–5 specimens. F = Frequent = 6–12 specimens. A = Abundant = More than 13 specimens.

Gypsina globulus. Similarly in the "*Orbiculina*" limestone, the total number of species increases to thirty-two in sample H and fifty in sample Vwl. The predominant species in these units are: *Clavulina pacifica, Textularia gramen, T. agglutinans, Quinqueloculina seminulum, Q. lamarckiana, Austrotrillina howchini, Elphidium indicum, Asterigerina dollfussi, A. planorbis, Cibicides lobatulus, Operculina bartschi, O. granulosa, Gypsina globulus, Sorites marginalis* and *Archaias angulatus*. It is interesting to note that *S. annectens* becomes rare concurrently with the introduction of "new species" and the increase in abundance of others.

The ecologically significant species occurring in these two units are: *C. pacifica, T. gramen, T. agglutinans, C. lobatulus, O. bartschi, O. granulosa, G. globulus, S. marginalis, A. angulatus, Q. lamarckiana, Q. seminulum*, and *Q. anguina* var. *arenata*.

Examination of the ecological data concerning the bathymetric distribution of *C. pacifica* suggests that it is a common Indo-Pacific species and that it is generally abundant in the coral-reef areas. Cushman (1924) recorded the species from Samoa at depths varying between 13 and 25 fathoms.

Cushman (1921, 1922, 1924) reported *T. gramen* and *T. agglutinans* at depths varying between 10 and 500 fathoms, the optimum depth being less than 50 fathoms. Said (1949) recorded *T. gramen* in the Gulf of Suez between 59 and 64 meters; Todd and Bronnimann (1957) reported it from offshore areas in the Eastern Gulf of Paria, between 2 and 18 fathoms.

C. lobatulus is a cosmopolitan species and is a common inhabitant in shallow waters, between 20 and 750 fathoms (Cushman, 1921, 1931). According to Lowman (1949), *Cibicides* is the most abundant genus in the midneritic zone.

Further ecological information is furnished by the distribution of *O. bartschi* and *O. granulosa*. Cushman (1921, 1933) recorded these species at depths varying between 3 and 52 fathoms. Concerning the distribution of operculines in general, Cushman (1930, p. 32) stated that " . . . they reach large size in the warm shallow waters of the Pacific." Similarly *G. globulus* is very common in the present day seas and is characteristic of coral reefs in the Indo-Pacific region at depths up to 17 fathoms (Cushman, 1924).

Examination of the data concerning the distribution of *S. marginalis* and *A. angulatus* indicates that these species attain large size and are particularly abundant in warm shallow waters between 12 and 52 fathoms (Cushman, 1924, 1930, 1933; Said, 1949).

An interesting feature of the fauna from the "*Orbiculina*" limestone is the occurrence of large numbers of species belonging to the family Miliolidae, some of which are restricted to this horizon. The most common species are *Q. seminulum, Q. lamarckiana* and *Q. anguina* var. *arenata*. *Q. seminulum* is known to inhabit a wide range of ecological conditions ranging from brackish-water to typically marine. The species, however, is more frequent in shallow temperate coastal waters of normal salinity. Similarly, data concerning the bathymetric distribution of *Q. lamarckiana* shows that the species is common at depths between 3 and 50 fathoms and is generally not common at greater depths (*vide* Cushman, 1921, 1922, 1924, 1932; Cushman & Moyer, 1930; Said, 1949; Parker *et al.*, 1953; Todd and Bronnimann, 1957). Cushman (1924) recorded *Q. anguina* var. *arenata* (= *Q. anguina* var. *agglutinans* auctorum *non* d'Orbigny) at depths between 17 and 50 fathoms while Said (1949) reported it from the Gulf of Suez and Red Sea between 59 and 450 metres.

Excepting *Austrotrillina howchini*, the remaining miliolid species are comparatively rare in these two units. The ecological data of some of these species are not sufficiently known as they do not survive to the present day. However, since *A. howchini* is fairly common, both in the Visawara and the "*Orbiculina*" limestones, it is obvious that it occupied the same ecological niche as that occupied by other miliolid species. These conclusions are in accordance with the views expressed by Norton (1930, p. 339) concerning the distribution of the Miliolidae as a whole that "The most favorable habitat for members of the Miliolidae is in warm shallow waters of tropical and warm temperate seas in depths down to perhaps 50–60 fathoms, where the temperature ranges between 20° and 26° C."

Thus the foraminiferal evidence suggests a relatively shallow marine environ-

ment with depth between 20 and 100 fathoms for the deposition of the Visawara and the "*Orbiculina*" limestones.

COMPOSITION AND AFFINITIES OF FAUNA

A total of sixty species and varieties belonging to thirty-two genera of fourteen families are recorded from the Miocene of Kathiawar; these include one new species—*Palmerinella raoi* (see Distribution Chart). Several forms are represented by specimens too poorly preserved to be definitely identified. The illustrations are camera lucida sketches by the senior author.

A substantial number of species are identical with or comparable to the Indo-Pacific forms, but relations are also indicated with the lower Miocene faunas of the Vienna Basin and south and southwestern France. The characteristic Indo-Pacific species which occur in the present material are: *Elphidium indicum, E. subinflatum, Bolivina marginoserrata, Streblus annectens, Cibicides tapanoeliensis* and *C. telisaensis*. Another well-known Indo-Pacific species—*Austrotrillina howchini*—has already been recorded from the Miocene beds of Kathiawar by Chatterji *et al.* (1953).

The genus *Geminaricta* which was hitherto known only from the Miocene of southern France and the Netherland West Indies, is being recorded for the first time from the Indo-Pacific region. The genus is represented by *G. virgata* var. *costifera*.

The fauna is also closely related to the Burdigalian fauna from the Surat-Broach area, described by Bhatia and Mandwal. Twelve species are common to the two regions.

SYSTEMATIC DESCRIPTIONS

Order FORAMINIFERA

Family TOLYPAMMINIDAE

Genus INVOLUTINA Terquem, 1862, emend. Loeblich & Tappan, 1954

INVOLUTINA sp. indet.

Text-fig. 1, fig. 1

Specimens of this indeterminate species were common in sample Vwl, Verawal. The wall is finely arenaceous.

Genus GLOMOSPIRA Rzehak, 1888

GLOMOSPIRA sp. indet.

Text-fig. 1, fig. 2

A few specimens which are referrable to this genus occur at Verawal.

Family TEXTULARIIDAE

Genus TEXTULARIA Defrance, 1824

TEXTULARIA AGGLUTINANS d'Orbigny

Text-fig. 1, figs. 3a,b

Textularia agglutinans D'ORBIGNY, 1839, *in* De La Sagra, Hist. Phys. Pol. Nat., Foraminifères, p. 144, pl. 1, figs. 17,18,32–34; SAID, 1949, Cush. Lab. Foram. Res., Spec. Publ., No. 26, p. 5, pl. 1, fig. 3.

This is a cosmopolitan species and occurs abundantly in samples Vwl (Verawal) and H (Bhogat); rare in sample Vf (Visawara).

TEXTULARIA GRAMEN d'Orbigny

Text-fig. 1, figs. 4a,b

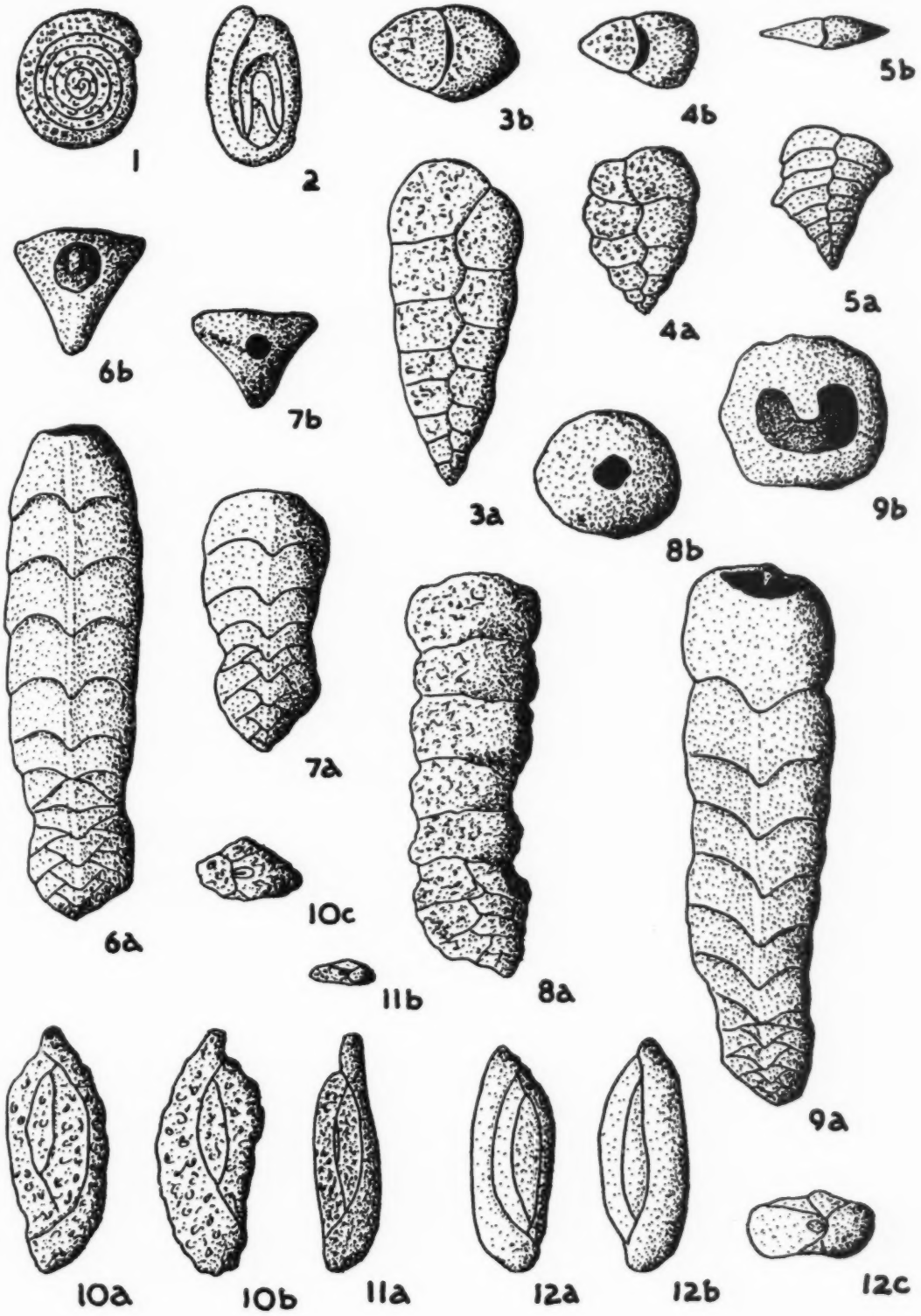
Textularia gramen D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 248, pl. 15, figs. 4–6; CUSHMAN, 1921, U. S. Nat. Mus., Bull. 100, v. 4, p. 105, pl. 20, fig. 7 (*et syn.*).

This is a widely distributed species, both in the fossil state and in the Recent seas. Abundant in samples Vwl and H, and rare in F and Vf.

EXPLANATION OF TEXT-FIG. *1*

All figures are ×42

FIG. *1*—*Involutina* sp. indet.
2—*Glomospira* sp. indet.
3—*Textularia agglutinans* d'Orbigny. a, side view; b, apertural view.
4—*Textularia gramen* d'Orbigny. a, side view; b, apertural view.
5—*Spiroplectammina* sp. indet. a, side view; b, apertural view.
6,7—*Clavulina pacifica* Cushman. *6*, adult specimen: a, side view; b, apertural view. *7*, juvenile specimen: a, side view; b, apertural view.
8—*Clavulina?* aff. *C. serventyi* Chapman and Parr. a, side view; b, apertural view.
9—*Clavulina angularis* d'Orbigny. a, side view; b, apertural view.
10—*Quinqueloculina anguina* (Terquem) var. *arenata* Said. a,b, opposite sides; c, apertural view.
11—*Quinqueloculina* aff. *Q. adelaidensis* Chapman & Parr var. *minuta* Keizer. a, side view; b, apertural view.
12—*Quinqueloculina laevigata* d'Orbigny. a,b opposite sides; c, apertural view.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7a
10c
11b
8a
9a
10a
10b
11a
12a
12b
12c

Genus SPIROPLECTAMMINA Cushman, 1927
SPIROPLECTAMMINA sp. indet.
Text-fig. 1, figs. 5a,b

A single specimen belonging to this genus was found in sample Vwl from Verawal. The test is compressed with a carinate, somewhat spinose periphery.

Family VALVULINIDAE
Genus CLAVULINA d'Orbigny, 1826
CLAVULINA ANGULARIS d'Orbigny
Text-fig. 1, figs. 9a,b

Clavulina angularis D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 268, no. 2, pl. 12, fig. 7; CUSHMAN, 1937, Cush. Lab. Foram. Res., Spec. Pub., no. 8, p. 19, pl. 2, figs. 29–33 (*et syn.*).

A few specimens referrable to this species were found in samples Vwl and H. The last chamber is rounded and the aperture has a distinct tooth.

CLAVULINA PACIFICA Cushman
Text-fig. 1, figs. 6a,b; 7a,b

Clavulina pacifica CUSHMAN, 1924, Carnegie Inst., Wash., Pub. 342, p. 22, pl. 6, figs. 7–11 (*et syn.*).

Typical specimens of this Indo-Pacific species occur in our material. The juvenile specimens (Text-fig. 1, figs. 7a,b) do not have any distinct tooth. These appear to be closely related to *Clavulinoides tricarinatus* LeRoy.

CLAVULINA? aff. C. SERVENTYI
Chapman & Parr
Text-fig. 1, figs. 8a,b

Clavulina serventyi CHAPMAN & PARR, 1935, Roy. Soc. Western Australia, Jour., v. 21, p. 5, pl. 1, fig. 7.

This is an indeterminate species, although closely related to *C. serventyi*. Our specimens lack a tooth, which is characteristic of the genus *Clavulina*.

Family MILIOLIDAE
GENUS QUINQUELOCULINA d'Orbigny, 1826
QUINQUELOCULINA ANGUINA (Terquem)
var. ARENATA Said
Text-fig. 1, figs. 10a,c

Quinqueloculina anguina (Terquem) var. *arenata* SAID, 1949, Contr. Cush. Lab. Foram. Res., Spec. Pub., no. 26, p. 9, pl. 1, fig. 25 (*et syn.*).

Frequent in sample Vwl. The wall is covered with coarsely agglutinated material.

QUINQUELOCULINA aff. Q. ADELAIDENSIS
Chapman & Parr var.
MINUTA Keizer
Text-fig. 1, figs. 11a,b

Quinqueloculina adelaidensis Chapman & Parr var. *minuta* KEIZER, 1945, Utrecht Univ., Geogr. Geol. Meded Physiogr.-geol. Recks., Utrecht, ser. 2, no. 6, p. 193, pl. 2, fig. 21.

A few specimens which may questionably be referred to this species were found in sample Vwl. The specimens are minute, elongate, with a long neck and a finely arenaceous coating on the wall.

QUINQUELOCULINA LAEVIGATA d'Orbigny
Text-fig. 1, figs. 12a–c

Quinqueloculina laevigata D'ORBIGNY, 1839, Barker Webb et Sabin Bertholot, Béthune, Paris, v. 2, p. 143, pl. 3, figs. 31–33; CUSHMAN, 1922, Carnegie Inst. Wash., Pub. 311, v. 17, p. 65, pl. 13, fig. 2.

A few specimens referable to this species were found in samples Vwl and H.

QUINQUELOCULINA LAMARCKIANA d'Orbigny
Text-fig. 2, figs. 1a–c

Quinqueloculina lamarckiana D'ORBIGNY, 1839, *in* De La Sagra, Hist. Phys. Pol. Nat., Fora-

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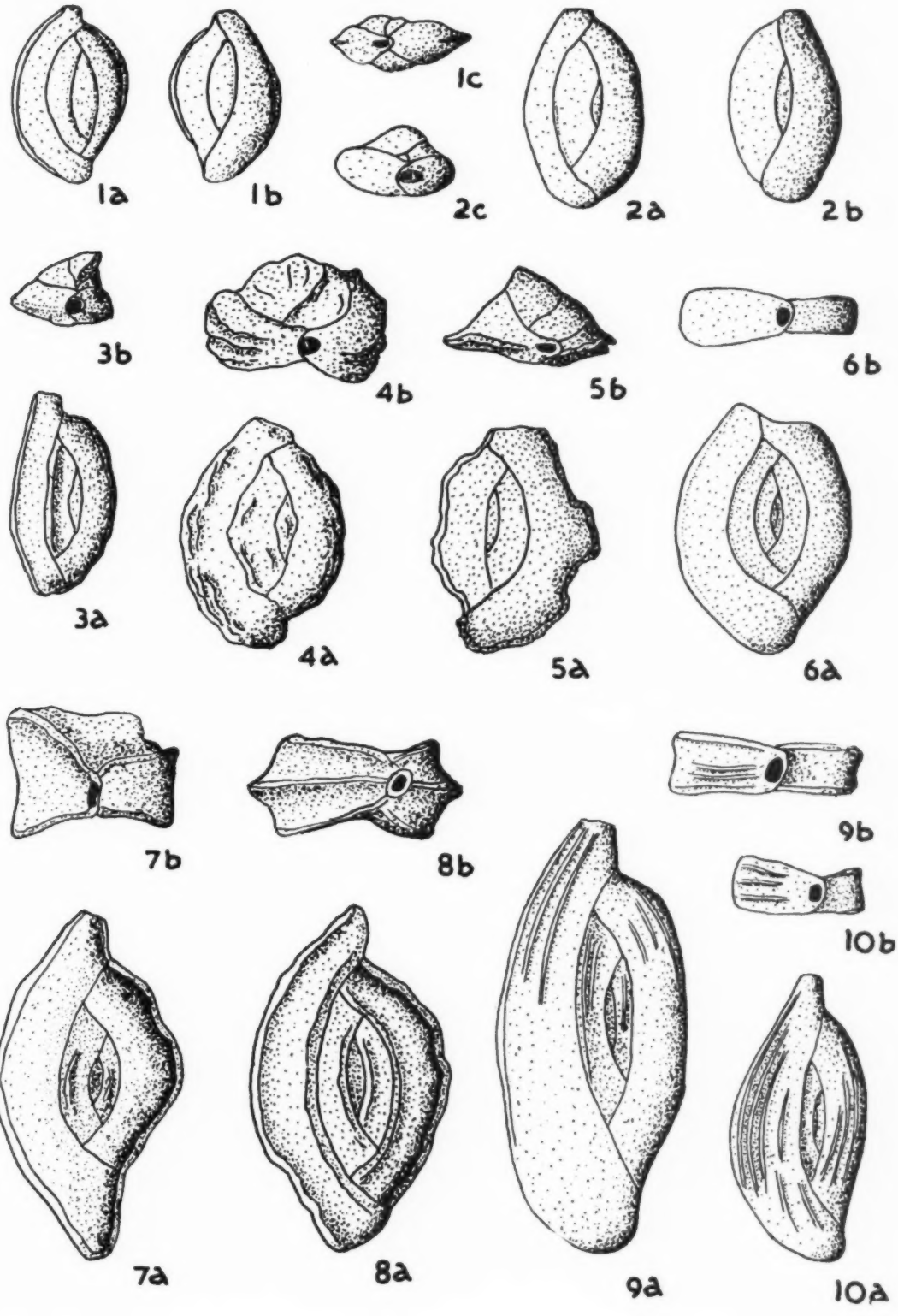
EXPLANATION OF TEXT-FIG. *2*

All figures are ×42

FIG. *1*—*Quinqueloculina lamarckiana* d'Orbigny. a,b, opposite sides; c, apertural view.
2—*Quinqueloculina seminulum* (Linnaeus). a,b, opposite sides; c, apertural view.
3—*Quinqueloculina venusta* Karrer. a, side view; b, apertural view.
4—*Quinqueloculina vermicularis* Karrer. a, side view; b, apertural view.
5—*Quinqueloculina* sp. indet. a, side view; b, apertural view.
6—*Spiroloculina excavata* d'Orbigny. a, side view; b, apertural view.
7—*Spiroloculina obscura* Cushman & Todd. a, side view; b, apertural view.
8—*Spiroloculina tricosta* Cushman & Todd. a, side view; b, apertural view.
9,10—*Spiroloculina* sp. indet. A. *9*, adult specimen: a, side view; b, apertural view. *10*, juvenile specimen: a, side view; b, apertural view.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4a
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9b
10b
7a
8a
9a
10a

minifères, p. 189, pl. 11, figs. 14–15; CUSHMAN, 1932, U. S. Nat. Mus., Bull. 161, pt. 1, p. 24, pl. 6, figs. 2a–c (*et syn.*).

This is a widely distributed species and occurs frequently in our material (sample Vwl). Bhatia (1956) recorded it from shore sands of western India.

QUINQUELOCULINA SEMINULUM (Linnaeus)
Text-fig. 2, figs. 2a–c

Serpula seminulum LINNAEUS, 1758, Systema Naturae, 10th ed., p. 786.
Quinqueloculina seminulum (Linnaeus) D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 303, no. 44; CUSHMAN, 1917, U. S. Nat. Mus., Bull. 71, pt. 6, p. 44, pl. 11, fig. 2.

This is a cosmopolitan species. Rare to frequent in Bhatia limestone (samples B and D) and abundant in "*Orbiculina*" limestone (samples H and Vwl).

QUINQUELOCULINA VENUSTA Karrer
Text-fig. 2, figs. 3a,b

Quinqueloculina venusta KARRER, 1868, Sitz. Akad. Wiss. Wien, v. 57, p. 147, pl. 2, fig. 6; CUSHMAN, 1921, U. S. Nat. Mus., Bull. 100, v. 4, p. 420, pl. 91, figs. 2a–c (*et syn.*); BHATIA, 1956, Contr. Cush. Found. Foram. Res., v. 7, pt. 1, p. 17, pl. 2, fig. 6.

This is a widely distributed species both in the fossil state and in the Recent seas. Bhatia (*op. cit.*) recorded it from Juhu and Bhogat beach, western India. Rare in sample H.

QUINQUELOCULINA VERMICULARIS Karrer
Text-fig. 2, figs. 4a,b

Quinqueloculina vermicularis KARRER, 1868, Sitz. Akad. Wiss. Wien, v. 58, p. 150, pl. 3, fig. 1.

Our specimens are similar to those figured by Karrer from the Miocene of Rumania. The surface is covered with irregular costae. Rare in sample H.

QUINQUELOCULINA sp. indet.
Text-fig. 2, figs. 5a,b

A few indeterminate specimens referrable to this genus were found at Verawal. The periphery has a frilled keel.

GENUS SIGMOILINA Schlumberger, 1887
SIGMOILINA TENUIS (Czjzek)
Text-fig. 3, fig. 3

Quinqueloculina tenuis CZJZEK, 1847, Haid. Nat. Abh., v. 2, p. 149, pl. 13, figs. 31–34.
Sigmoilina tenuis (Czjzek) CUSHMAN, 1929, Contr. Cush. Lab. Foram. Res., v. 5, pt. 4, p. 81, pl. 12, figs. 12–14.

Rare in sample Vwl.

Genus SPIROLOCULINA d'Orbigny, 1826
SPIROLOCULINA EXCAVATA d'Orbigny
Text-fig. 2, figs. 6a,b

Spiroloculina excavata D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 271, pl. 16, figs. 19–21; CUSHMAN & TODD, 1944, Cush. Lab. Foram. Res., Spec. Pub., no. 11, p. 23, pl. 4, figs. 12–16 (*et syn.*).

Typical specimens of this species which was originally described from the Miocene of the Vienna Basin, occur at Verawal. It is a cosmopolitan species and ranges from Miocene to Recent.

SPIROLOCULINA OBSCURA Cushman & Todd
Text-fig. 2, figs. 7a,b

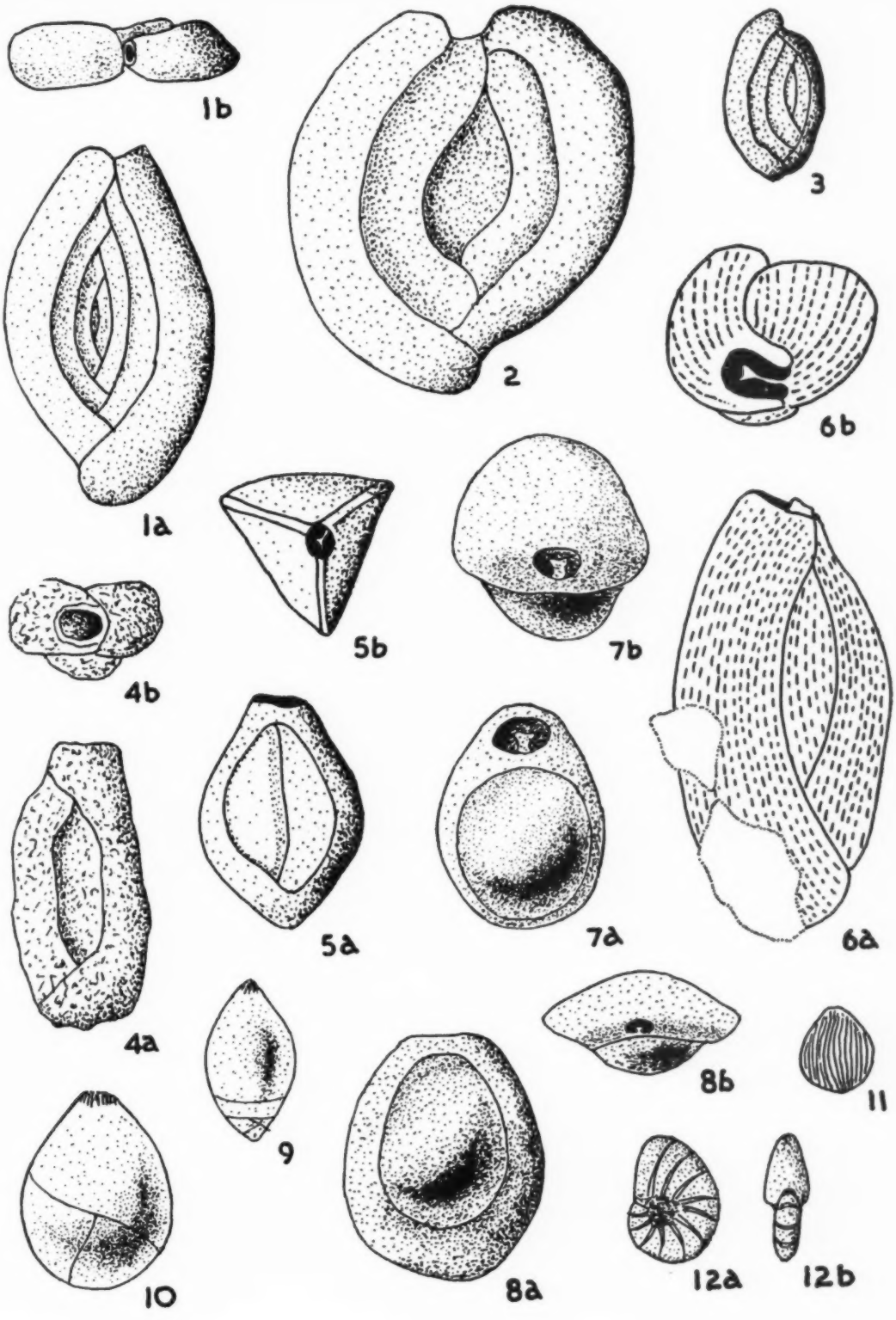
Spiroloculina obscura CUSHMAN & TODD, 1944, Contr. Cush. Found. Foram. Res., Spec. Pub. no. 11, p. 20, pl. 1, fig. 8; pl. 3, figs. 22–25 (*et syn.*).

Rare in sample N.

EXPLANATION OF TEXT-FIG. 3

All figures are ×42

FIG. 1—*Spiroloculina* sp. indet. B. a, side view; b, apertural view.
2—*Spiroloculina* sp. indet. C.
3—*Sigmoilina tenuis* (Czjzek).
4—*Triloculina garretti* Howe. a, side view; b, apertural view.
5—*Triloculina tricarinata* d'Orbigny. a, side view; b, apertural view.
6—*Triloculina* aff. *T. rupertiana* (Brady). a, side view; b, apertural view.
7—*Pyrgo bulloides* (d'Orbigny). a, side view; b, apertural view.
8—*Pyrgo* sp. indet. a, side view; b, apertural view.
9—*Glandulina laevigata* d'Orbigny.
10—*Globulina gibba* d'Orbigny.
11—*Lagena* cf. *L. striata* (d'Orbigny).
12—*Nonion boueanum* (d'Orbigny). a, side view; b, apertural view.


1b
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5b
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4b
6a
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7a
4a
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8b
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8a
12a
12b

SPIROLOCULINA TRICOSTA Cushman & Todd
Text-fig. 2, figs. 8a,b

Spiroloculina tricosta CUSHMAN & TODD, 1944, *Ibid.*, p. 9,10,21, pl. 1, fig. 9; pl. 3, figs. 26–29 (*et syn.*).

Typical specimens of this species were found at Bhogat (sample H). The species was originally described from the Miocene of the Paris Basin. Kaasschieter (1955) recorded it from the Aquitanian-Burdigalian of southwestern France.

SPIROLOCULINA sp. indet. A
Text-fig. 2, figs. 9,10

Frequent to rare specimens of this indeterminate species were found in samples H and Uwl from the "*Orbiculina*" limestone. The surface of the test is covered by faint costae. The periphery in the juvenile specimens (Text-fig. 2, fig. 10) is convex; in the adult it becomes slightly carinate (Text-fig. 2, fig. 9). The species appears to be closely related to *S. corrugata* Cushman & Todd.

SPIROLOCULINA sp. indet. B
Text-fig. 3, figs. 1a,b

A single specimen of this indeterminate species was found in sample D from the Bhatia limestone. The species somewhat vaguely resembles *S. concava* Petri.

SPIROLOCULINA sp. indet. C
Text-fig. 3, fig. 2

This is another indeterminate species. Rare in sample F from the Bhatia limestone.

Genus TRILOCULINA d'Orbigny, 1826
TRILOCULINA GARRETTI Howe
Text-fig. 3, figs. 4a,b

Triloculina garretti HOWE, 1939, Louisiana Dept. Conservation Geol. Surv., Bull. New Orleans, no. 14, p. 37, pl. 2, figs. 3–5.

Rare in sample Vwl.

TRILOCULINA aff. T. RUPERTIANA (Brady)
Text-fig. 3, figs. 6a,b

Miliolina rupertiana BRADY, 1884, Rept. Voy. *Challenger*, Zoology, v. 9, pl. 7, figs. 3–12.

Rare in "*Orbiculina*" limestone. Similar forms were reported by Bhatia (1956) from the Juhu beach sand, Bombay.

TRILOCULINA TRICARINATA d'Orbigny
Text-fig. 3, figs. 5a,b

Triloculina tricarinata D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 229, no. 7; CUSHMAN, 1929, U. S. Nat. Mus., Bull. 104, pt. 6, p. 56, pl. 13, figs. 3a–c.

This is a cosmopolitan species. Rare in samples Vwl and H.

Genus PYRGO Defrance, 1824
PYRGO BULLOIDES (d'Orbigny)
Text-fig. 3, figs. 7a,b

Biloculina bullloides D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 297, pl. 16, figs. 1–4.
Pyrgo bulloides (d'Orbigny) MARKS, 1951, Contr. Cush. Found. Foram. Res., v. 2, pt. 2, p. 41 (*et syn.*).

This is a cosmopolitan species both in the fossil state and in the Recent seas. It was originally described from the Miocene of France. Also reported from the Miocene of the Vienna Basin and southwestern France. Typical specimens were found in the "*Orbiculina*" limestone.

PYRGO sp. indet.
Text-fig. 3, figs. 8a,b

Rare in sample Vwl. The test is compressed with subacute periphery.

Family LAGENIDAE
Genus LAGENA Walker & Jacob, 1798
LAGENA cf. L. STRIATA (d'Orbigny)
Text-fig. 3, fig. 11

Oolina striata D'ORBIGNY, 1839, Voyage dans l'Amérique méridionale, v. 5, pt. 5, p. 21, pl. 5, fig. 12.

A single specimen which may questionably be referred to this species was found at Verawal. The surface is finely striate.

Family POLYMORPHINIDAE
Subfamily POLYMORPHININAE
Genus GLANDULINA d'Orbigny, 1826
GLANDULINA LAEVIGATA d'Orbigny
Text-fig. 3, fig. 9

Nodosaria (*Glandulina*) *laevigata* D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 252, pl. 10, figs. 1–3.
Glandulina laevigata D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 29, pl. 1, figs. 4,5.

Typical specimens of this species were found in sample Vwl. Rare in occurrence.

Genus GLOBULINA d'Orbigny, 1839
GLOBULINA GIBBA d'Orbigny
Text-fig. 3, fig. 10

Polymorphina (Globulina) gibba D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 266, no. 10, modèles no. 63.
Globulina gibba D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 227, pl. 13, figs. 13–14.

Frequent specimens of this widely distributed species occur at Verawal.

Family NONIONIDAE
Genus NONION Montfort, 1808
NONION BOUEANUM (d'Orbigny)
Text-fig. 3, figs. 12a,b

Nonionina boueana D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 108, pl. 5, figs. 11,12.
Nonion boueanum (d'Orbigny) CUSHMAN, 1939, U. S. Geol. Surv., Prof. Paper 191, p. 12, pl. 3, figs. 7,8.

This is a cosmopolitan species. Excepting size (the Kathiawar specimens being smaller) our specimens are identical with topotype specimens from the Miocene of the Vienna Basin.

Genus ELPHIDIUM Montfort, 1808
ELPHIDIUM INDICUM Cushman
Text-fig. 4, figs. 1a,b

Elphidium indicum CUSHMAN, 1956, Contr. Cush. Lab. Foram. Res., v. 12, p. 83, pl. 14, figs. 10a,b; BHATIA, 1956, Contr. Cush. Found. Foram. Res., v. 7, pt. 1, p. 20, pl. 5, fig. 12.

This is a well-known Indo-Pacific species. Frequent to abundant specimens were found in all the samples. Bhatia and Mandwal reported the species from the Burdigalian of Surat-Broach area.

ELPHIDIUM SUBINFLATUM Cushman
Text-fig. 4, figs. 2a,b

Elphidium subinflatum CUSHMAN, 1936, Contr. Cush. Lab. Foram. Res., v. 12, p. 84, pl. 15, figs. 1a,b.

This species was originally described from the Miocene Filter Quarries, Batesford, Victoria, Australia. Rare in sample H.

Family BULIMINIDAE
Subfamily REUSSELLINAE
Genus REUSSELLA Galloway, 1933
REUSSELLA SPINULOSA (Reuss)
Text-fig. 4, fig. 4

Verneulina spinulosa REUSS, 1850, Denkschr. K. Akad. Wiss. Wien, v. 1, p. 374, pl. 47, fig. 12.
Reussella spinulosa (Reuss) CUSHMAN, 1945, Contr. Cush. Lab. Foram. Res., v. 21, p. 33, pl. 6, figs. 8,9.

In our material it became difficult to separate *R. spinulosa* and *R. pulchra;* the latter being a minor variant of *R. spinulosa.* The species was originally described from the Miocene of the Vienna Basin and ranges from Miocene to Recent. Rare in the "*Orbiculina*" limestone.

REUSSELLA SPINULOSA (Reuss) var.
LAEVIGATA Cushman
Text-fig. 4, fig. 3

Reussella spinulosa (Reuss) var. *laevigata* CUSHMAN, 1945, Contr. Cush. Lab. Foram. Res.,v. 21, pt. 2, p. 34, pl. 6, figs. 11,12.

A few specimens referable to this species were found in samples Vwl and H. Recorded from the Miocene of the Vienna Basin and southwestern France.

REUSSELLA sp. indet.
Text-fig. 4, figs. 5a,b

Rare specimens of this indeterminate species occur at Verawal. The specimens are elongate, triserial throughout, and carinate.

Subfamily VIRGULININAE
Genus BOLIVINA d'Orbigny, 1839
BOLIVINA MARGINOSERRATA LeRoy
Text-fig. 4, fig. 6

Bolivina marginoserrata LEROY, 1939, Nat. Tijd. Ned.-Indie, v. 99, p. 247, pl. 4, figs. 8,9.

Rare in sample Vwl. It was originally described from the Neogene (Miocene?) of the Telisa formation, Central Sumatra, Indonesia.

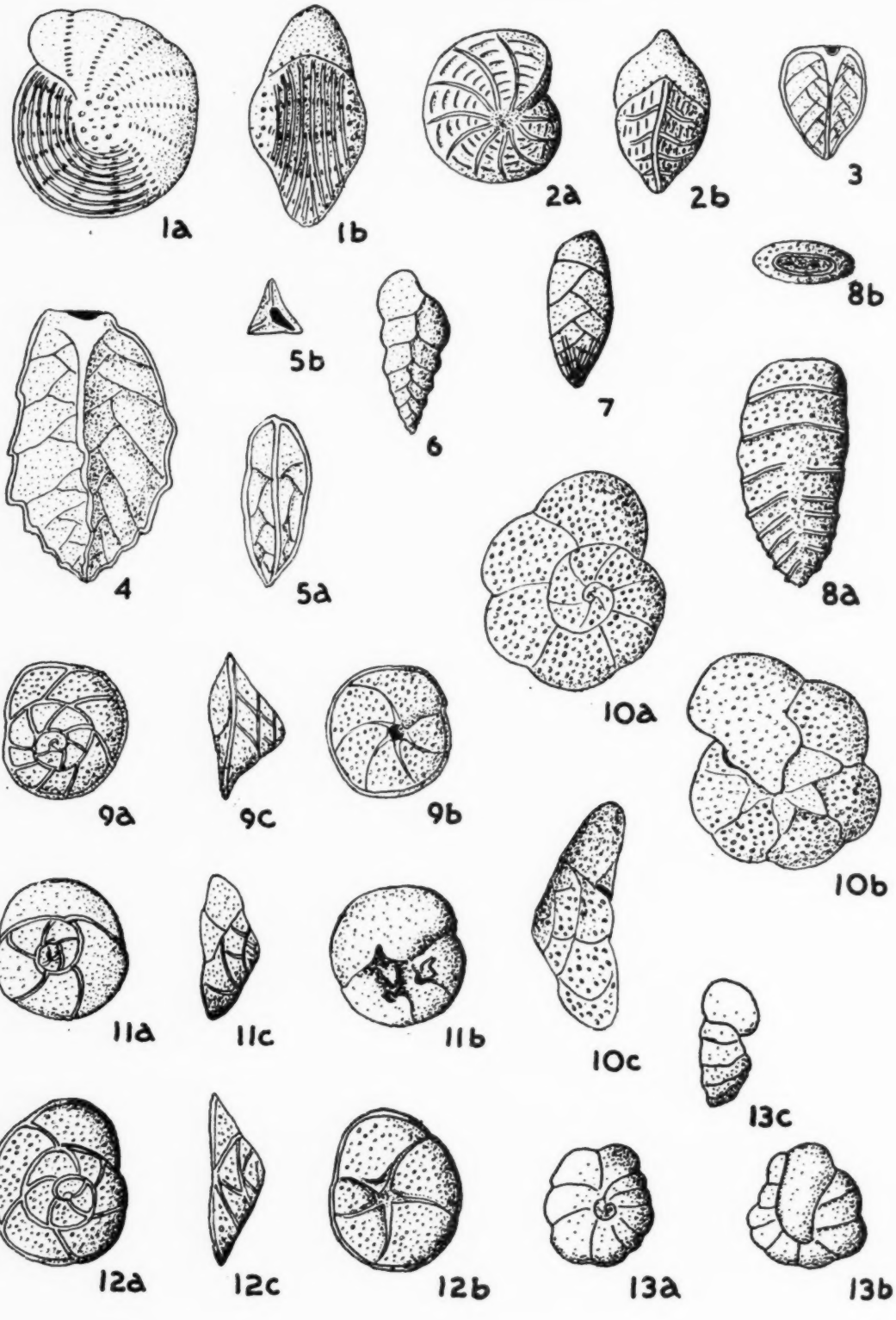
Genus LOXOSTOMUM Ehrenberg, 1854
LOXOSTOMUM sp. indet.
Text-fig. 4, fig. 7

A single specimen referable to this genus was found in sample Vwl. The test is finely perforate with a few costae in the initial portion.

Genus GEMINARICTA Cushman, 1936
GEMINARICTA VIRGATA (Cushman) var.
COSTIFERA Cushman
Text-fig. 4, figs. 8a,b

Geminaricta virgata (Cushman) var. *costifera* CUSHMAN, 1936, Cush. Lab. Foram. Res., Spec. Pub. no. 6, p. 62, pl. 8, figs. 19a,b; CUSHMAN, 1937, *Ibid.*, no. 9, p. 209, pl. 23, figs. 33,34.

This is the first record of the genus from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13c

the Indo-Pacific region. It was originally described from the Miocene (Burdigalian) of St. Paul de Dax, Landes, France. Concerning the distribution of the genus, Cushman (1937, p. 208) stated: "As far as known, this genus is a specialized one developed in the Miocene of southern France. The twinned apertures are a constant character, and are usually easily determined. It is possible that this genus may be found in the Indo-Pacific or Australian regions, as other forms of the Miocene of France show this range."

Frequent in sample Vwl.

Family ROTALIIDAE
Subfamily DISCORBINAE
Genus DISCORBIS Lamarck, 1804
DISCORBIS aff. D. AUSTRALIS Parr
Text-fig. 4, figs. 12a–c

Discorbis australis Parr, 1932, Roy. Soc. Victoria, Proc., v. 44, p. 227, pl. 22, fig. 31.

A few specimens which may questionably be referred to this species were found in sample Vwl. This species is closely related to *D. mira* Cushman which was also found in the same sample. However, it is possible that the two species, as represented in our material, may be dimorphic generations. More specimens are required before this can be ascertained.

DISCORBIS BRACTIFERA Le Calvez
Text-fig. 4, figs. 10a–c

Discorbis bractifera LECALVEZ, 1949, Serv. Carte Géol. Mém. Paris, II, p. 18, pl. 3, figs. 39–41.
Bucella? sp. indet. BHATIA & MANDWAL, (MS.), Jour. Pal. Soc. India, v. 2 (in press).

Specimens similar to the present species were questionably referred to the genus *Bucella* Andersen by Bhatia & Mandwal (*op. cit.*). Rare to frequent in samples F, Vf, and H. It was originally described from the Eocene of the Paris Basin.

DISCORBIS GLOBULARIS (d'Orbigny)
var. BRADYI Cushman
Text-fig. 4, figs. 11a–c

Discorbis globularis (d'Orbigny) var. *bradyi* CUSHMAN, 1915, U. S. Nat. Mus., Bull. 71, pt. 5, p. 12, pl. 8, fig. 1.

Rare in samples H and Vwl.

DISCORBIS MIRA Cushman
Text-fig. 4, figs. 9a–c

Discorbis mira CUSHMAN, 1922, Carnegie Inst. Wash., Pub. 311, p. 39, pl. 6, figs. 10,11.

Rare in sample Vwl.

Genus VALVULINERIA Cushman, 1926
VALVULINERIA CALIFORNICA Cushman
Text-fig. 4, figs. 13a–c

Valvulineria californica CUSHMAN, 1926, Contr. Cush. Lab. Foram. Res., v. 2, pt. 3, p. 60, pl. 9, fig. 1.

Rare in sample H. Our specimens are identical with the topotype specimens.

Subfamily ROTALIINAE
Genus ROTALIA Lamarck, 1804
ROTALIA aff. R. SUMATRANA LeRoy
Text-fig. 5, fig. 1

Rotalia sumatrana LEROY, 1944, Quart. Colorado School of Mines, v. 39, no. 3, p. 35, pl. 2, figs. 34–36.

Rare in "*Orbiculina*" limestone.

EXPLANATION OF TEXT-FIG. *4*

All figures are ×42

FIG. *1*—*Elphidium indicum* Cushman. a, side view; b, apertural view.
2—*Elphidium subinflatum* Cushman. a, side view; b, apertural view.
3—*Reussella spinulosa* (Reuss) var. *laevigata* Cushman.
4—*Reussella spinulosa* (Reuss).
5—*Reussella* sp. indet. a, side view; b, apertural view.
6—*Bolivina marginoserrata* LeRoy.
7—*Loxostomum* sp. indet.
8—*Geminaricta virgata* (Cushman) var. *costifera* Cushman. a, side view; b, apertural view.
9—*Discorbis mira* Cushman. a, dorsal view; b, ventral view; c, apertural view.
10—*Discorbis bractifera* Le Calvez. a, dorsal view; b, ventral view; c, apertural view.
11—*Discorbis globularis* (d'Orbigny) var. *bradyi* Cushman. a, dorsal view; b, ventral view; c, apertural view.
12—*Discorbis* aff. *D. australis* Parr. a, dorsal view; b, ventral view; c, apertural view.
13—*Valvulineria californica* Cushman. a, dorsal view; b, ventral view; c, apertural view.

Genus STREBLUS Fischer, 1817
STREBLUS ANNECTENS (Parker & Jones)
Text-fig. 5, figs. 2a–c

Rotalia beccarii (Linnaeus) var. *annectens* PARKER & JONES, 1865, Philos. Trans., v. 155, p. 387,422, pl. 19, figs. 11a–c.

Typical specimens of this species were found in all the samples. Abundant in Bhatia limestone and rare in Visawara and "*Orbiculina*" limestones. The protoforamen and the deuteroforamen (*vide* Bhatia, *loc. cit.*) are generally not clearly seen due to the filling by rock matrix. Bhatia & Mandwal recorded it from the Burdigalian of the Surat-Broach area.

STREBLUS sp. indet.
Text-fig. 5, figs. 3a–c

Rare in the "*Orbiculina*" limestone.

Genus EPONIDES Montfort, 1808
EPONIDES sp. indet.
Text-fig. 5, figs. 7a–b

Rare in the "*Orbiculina*" limestone.

Family AMPHISTEGINIDAE
Genus ASTERIGERINA d'Orbigny, 1839
ASTERIGERINA DOLLFUSSI Cushman
Text-fig. 5, figs. 4a–c

Asterigerina dollfussi CUSHMAN, 1928, Bull. Soc. Sci. Seine-et-Oise, sér. 2, v. 9, p. 56, pl. 3, figs. 4a–c.

Typical specimens of this species occur abundantly in the "*Orbiculina*" limestone. The types of the species were from the Stampian of Jeure, Paris Basin. Kaasschieter (1955) recorded it from the Stampian of southwestern France. Bhatia & Mandwal described it from the Burdigalian of the Surat-Broach area.

ASTERIGERINA PLANORBIS d'Orbigny
Text-fig. 5, figs. 5a–c

Asterigerina planorbis D'ORBIGNY, 1846, Foram. Foss. Bassin Tert. Vienne, p. 205, pl. 11, figs. 1–3; MARKS, 1951, Contr. Cush. Found. Foram. Res., v. 2, pt. 2, p. 66, pl. 8, fig. 1a–c.

Excepting size (the Kathiawar specimens being smaller), our specimens are identical with the topotypes from The Miocene of the Vienna Basin. Also recorded from the Aauitanian-Burdigalian of southwestern France (Kaasschieter, 1955, p. 90). Irregularly distributed.

Family GLOBIGERINIDAE
Subfamily GLOBIGERININAE
Genus GLOBIGERINOIDES Cushman, 1927
GLOBIGERINOIDES TRILOBA (Reuss)
Text-fig. 6, fig. 1

Globigerina triloba REUSS, 1850, Denkschr. K. Akad. Wiss. Wien, v. 1, p. 374, pl. 47, fig. 11.
Globigerinoides triloba (Reuss) CORYELL & MOSSMAN, 1942, Jour. Paleontology, v. 16, p. 238, pl. 36, figs. 29–30.

In our material it was difficult to differentiate between *G. triloba* and *G. trilocularis*. Frequent in sample Vwl.

Family GLOBOROTALIIDAE
Genus GLOBOROTALIA Cushman, 1927
GLOBOROTALIA cf. G. MENARDII (d'Orbigny)
Text-fig. 5, figs. 6a,b

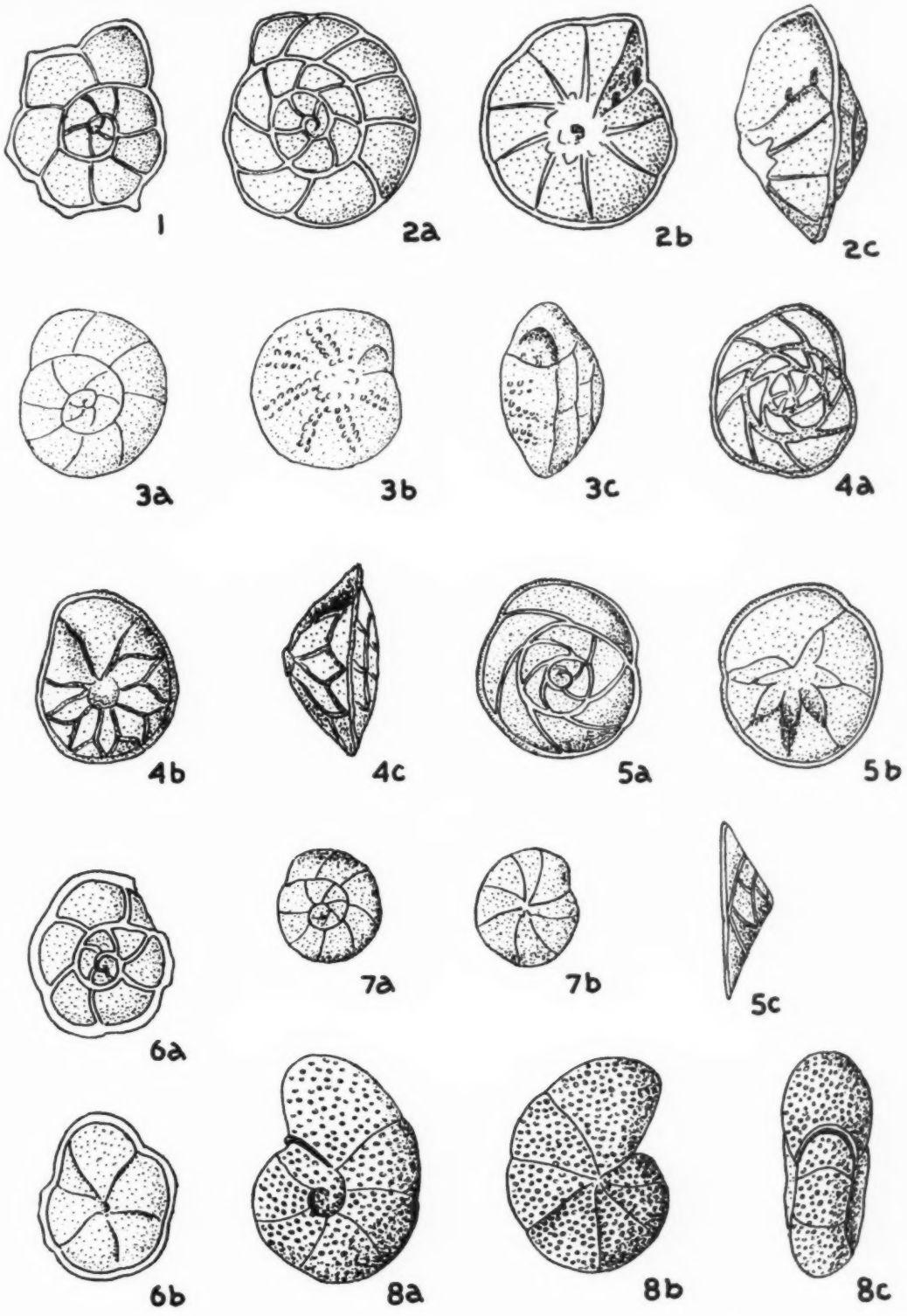
Rotalia menardii D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 273, modèles no. 10.
Globorotalia menardii (d'Orbigny) TODD & BRONNIMANN, 1957, Cush. Found. Foram. Res., Spec. Pub. no. 3, p. 41, pl. 12, fig. 8.

A few specimens which may questionably be referred to this species occur at Verawal.

EXPLANATION OF TEXT-FIG. 5

All figures are ×42

FIG. 1—*Rotalia* aff. *R. sumatrana* LeRoy.
2—*Streblus annectens* (Parker & Jones). a, dorsal view; b, ventral view; c, apertural view.
3—*Streblus* sp. indet.
4—*Asterigerina dollfussi* Cushman. a, dorsal view; b, ventral view; c, apertural view.
5—*Asterigerina planorbis* d'Orbigny. a, dorsal view; b, ventral view; c, apertural view.
6—*Globorotalia* cf. *G. menardii* (d'Orbigny). a, dorsal view; b, ventral view.
7—*Eponides* sp. indet. a, dorsal view; b, ventral view.
8—*Anomalina grosserugosa* (Gümbel). a, dorsal view; b, ventral view; c, apertural view.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8b
8c

Family ANOMALINIDAE
Subfamily ANOMALININAE
Genus ANOMALINA d'Orbigny, 1826
ANOMALINA GROSSERUGOSA (Gümbel)
Text-fig. 5, figs. 8a–c

Truncatulina grosserugosa GÜMBEL, 1868, Abh. K. Akad. Wiss. München, v. 10, p. 82, pl. 2, fig. 104a,b.
Anomalina grosserugosa (Gümbel) HAGN & HOLZL, 1952, Bayer. Geol. Landesamt no. 10, p. 184.

This is a widely distributed species and ranges from Eocene to Recent. Frequent in sample H.

Genus PALMERINELLA Bermudez, 1934
PALMERINELLA RAOI Bhatia & Mohan, n. sp.
Text-fig. 6, figs. 3a,b

Diagnosis.—The test is compressed, planispiral, and nearly evolute on both the sides with three to four whorls visible; the periphery is subacute, and lobulate; there are twelve to fourteen chambers in the final whorl, and they gradually increase in size with growth; the sutures are straight or gently curved and limbate; the wall is calcareous and finely perforate; the aperture is narrow and elongate, extending the length of the apertural face.

Dimensions.—Length up to 0.71 mm.; breadth up to 0.57 mm.; thickness up to 0.11 mm.

Types.—The holotype (Text-fig. 6, figs. 3a,b) measures 0.71 mm. in length, 0.57 mm. in breadth, and 0.11 mm. in thickness. The types will be deposited at a later date in the Paleontological collection of the Geological Survey of India, Calcutta.

Occurrence.—The types come from the hard, yellowish marly limestone exposed 1½ miles west of Khorasa village, in the Verawal area, Kathiawar. In all, seven specimens were collected.

Discussion.—This is a very distinctive species. It differs from the well-known *Palmerinella palmerae* Bermudez in having more whorls, fewer chambers, lobulate periphery and bi-umbilicate, compressed test.

Remarks.—The species is named in honor of Prof. S. R. N. Rao, Department of Geology, Lucknow University, for his help and guidance.

Genus ANOMALINELLA Cushman, 1927
ANOMALINELLA ROSTRATA (Brady)
Text-fig. 6, figs. 2a,b

Truncatulina rostrata BRADY, 1881, Quart. Jour. Micr. Sci., London, n.s., v. 21, p. 65.
Anomalinella rostrata (Brady) CUSHMAN, 1927, Contr. Cush. Lab. Foram. Res., vol. 3, p. 93; Foraminifera: their Classification and Economic Use, Harvard Univ. Press, p. 335, pl. 28, fig. 6, Key Pl. 36, fig. 8.

Typical specimens of this species occur in majority of the samples. It is particularly well developed and abundant in sample H, from the "*Orbiculina*" limestone. The test is coarsely perforate and involute on both the sides. The sutures are distinctly limbate and raised. The periphery is keeled. The supplementary aperture in some specimens runs parallel to the periphery. It is usually not clearly observable, but becomes distinct on staining. This is the first record of the species from India.

Subfamily CIBICIDINAE
Genus CIBICIDES Montfort, 1808
CIBICIDES LOBATULUS (Walker & Jacob)
Text-fig. 6, figs. 4a–c

Nautilus lobatulus WALKER & JACOB, 1798, Adams Essays, Kanmachers ed., p. 642, pl. 14, fig. 36.
Cibicides lobatulus (Walker & Jacob) CUSHMAN, 1931, U. S. Nat. Mus., Bull. 104, pt. 8, p. 118, pl. 21, fig. 3 (*et syn.*).

Rare to abundant in the Visawara and "*Orbiculina*" limestones. The species shows

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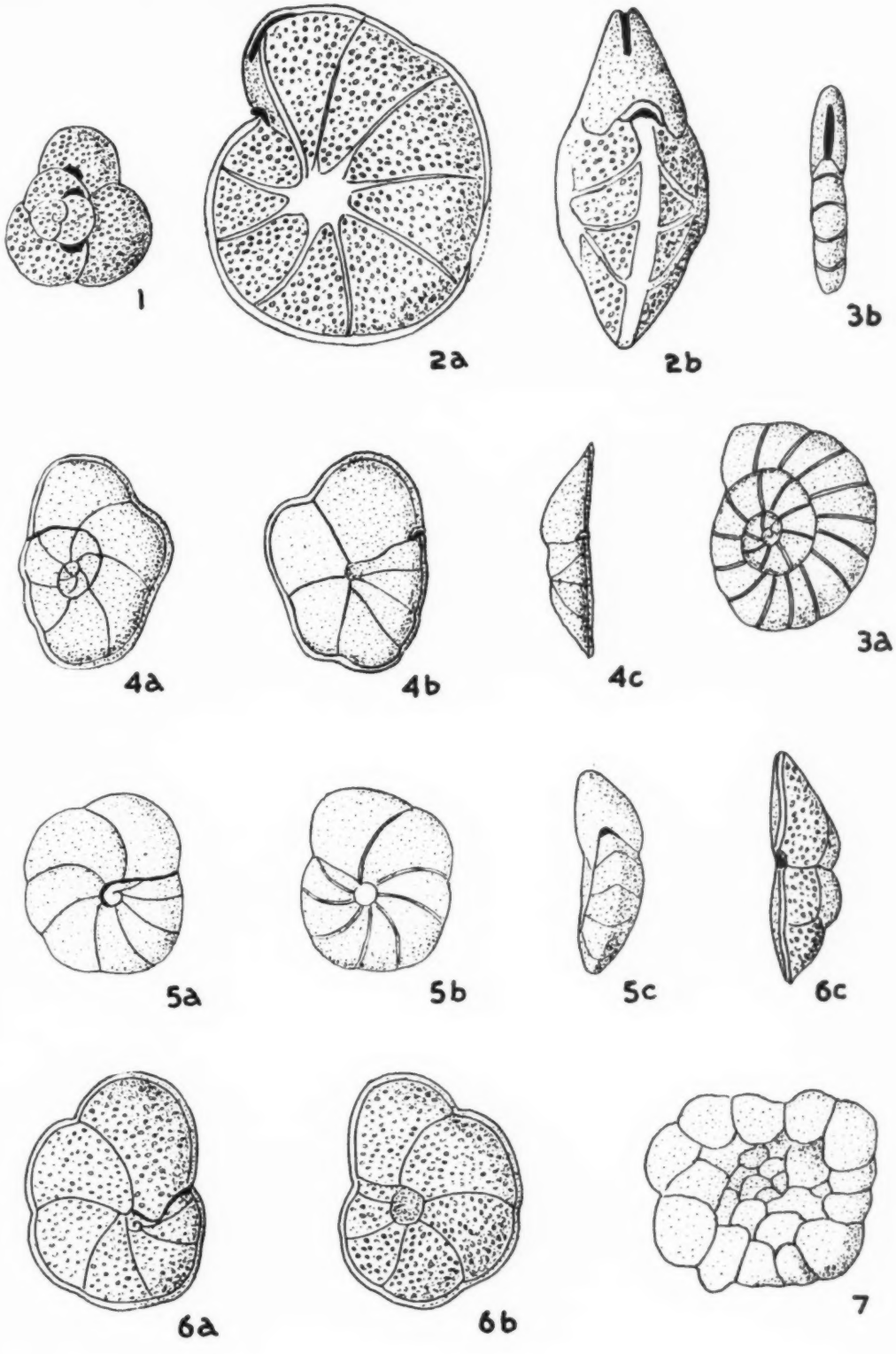
EXPLANATION OF TEXT-FIG. *6*

All figures are ×42

FIG. *1*—*Globigerinoides triloba* (Reuss).
2—*Anomalinella rostrata* (Brady). a, side view; b, apertural view.
3—*Palmerinella raoi* Bhatia & Mohan, n. sp. Holotype. a, side view; b, apertural view.
4—*Cibicides lobatulus* (Walker & Jacob). a, dorsal view; b, ventral view; c, apertural view.
5—*Cibicides tapanoeliensis* LeRoy. a, dorsal view; b, ventral view; c, apertural view.
6—*Cibicides telisaensis* LeRoy. a, dorsal view; b, ventral view; c, apertural view.
7—*Planorbulina mediterranensis* d'Orbigny.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4a
4b
4c
3a
5a
5b
5c
6c
6a
6b
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considerable variation in the degree of concavity of the dorsal side.

CIBICIDES TAPANOELIENSIS LeRoy
Text-fig. 6, figs. 5a–c

Cibicides tapanoeliensis LEROY, 1939, Nat. Tijd. Ned.-Indie, v. 6, p. 270, pl. 7, figs. 19–20.

The species was originally recorded from the Miocene of Central Sumatra. Bhatia & Mandwal recorded it from the Burdigalian of the Surat-Broach area. Abundant in sample Vwl.

CIBICIDES TELISAENSIS LeRoy
Text-fig. 6, figs. 6a–c

Cibicides telisaensis LEROY, 1939, Nat. Tijd. Ned.-Indie, v. 6, p. 271, pl. 8, figs. 16–18.

Abundant in sample Vwl.

Family PLANOBULINIDAE
Genus PLANORBULINA d'Orbigny, 1826
PLANORBULINA MEDITERRANENSIS
d'Orbigny
Text-fig. 6, fig. 7

Planorbulina mediterranensis D'ORBIGNY, 1826, Ann. Sci. Nat., v. 7, p. 280, no. 2, pl. 14, figs. 4–6; 1846, Foram. Foss. Bassin Tert. Vienne, p. 166, pl. 9, figs. 15–17.

This is a widely distributed species. Rare in samples H and Vwl.

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 662–669, PLS. 83–86, 4 TEXT-FIGS., JULY 1959

MIOCENE FORAMINIFERA FROM THE TEMBLOR FORMATION NORTH OF COALINGA, CALIFORNIA

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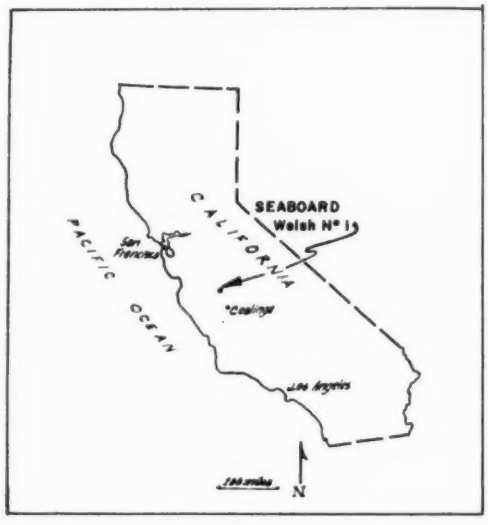
ABSTRACT—The occurrence of 34 foraminiferal species from the Temblor formation, cored in a well north of Coalinga, California, is described. This fauna is divisible into two parts, Miocene in age and representing a shallow environment of deposition. Three species and one variety are described as new: *Glabratella becki*, *Siphonina temblorensis*, *Epistominella nova*, n. spp.; *Nonionella limbato-striata* Cushman *evoluta* n. var.

INTRODUCTION

A FORAMINIFERAL fauna is described and figured from the Miocene Temblor formation of the San Joaquin Valley, California. This fauna occurs in a 455 foot (2843′ to 3298′) sandy interval cored in the Seaboard Oil Company (now succeeded by The Texas Company) Welsh No. 1, S. 10, T. 16 S., R. 13 E., M. D. B. & M., north of Coalinga, Fresno County, California (Text-fig. 1).

In this area the Temblor is unconformably overlain by the Pliocene undifferentiated Jacalitos-Etchegoin formations (Schoellhamer & Kinney, 1953). The Temblor unconformably overlies the Oligocene Tumey formation (Atwill, 1935). This latter relationship was noted by the early workers Anderson & Pack (1915, p. 76):

> South of Panoche Creek it ["Kreyenhagen," equals Tumey] is overlain by the Vaqueros formation [equals Temblor] . . . , with which it shows distinct angular unconformity. This



TEXT-FIG. 1—Map of California showing location of the Seaboard Oil Co., Welsh No. 1.

EXPLANATION OF PLATE 83

FIG. 1—*Cornuspira* sp. *a*, Side view; *b*, peripheral view; ×59; from the Upper Part, 2950–2976′ tray 1.

2—*Quinqueloculina akneriana* d'Orbigny. *a,b*, Side views; *c*, apertural view; ×46; from the Upper Part, 2950–2976′ tray 1.

3—*Massilina pratti* Cushman & Ellisor. *a*, Side view; *b*, apertural view; ×67; from the Upper Part, 2950–2976′ tray 1.

4—*Triloculina nitens* Reuss. *a,b*, Side views; *c*, apertural view; ×62; from the Upper Part, 2950–2976′ tray 1.

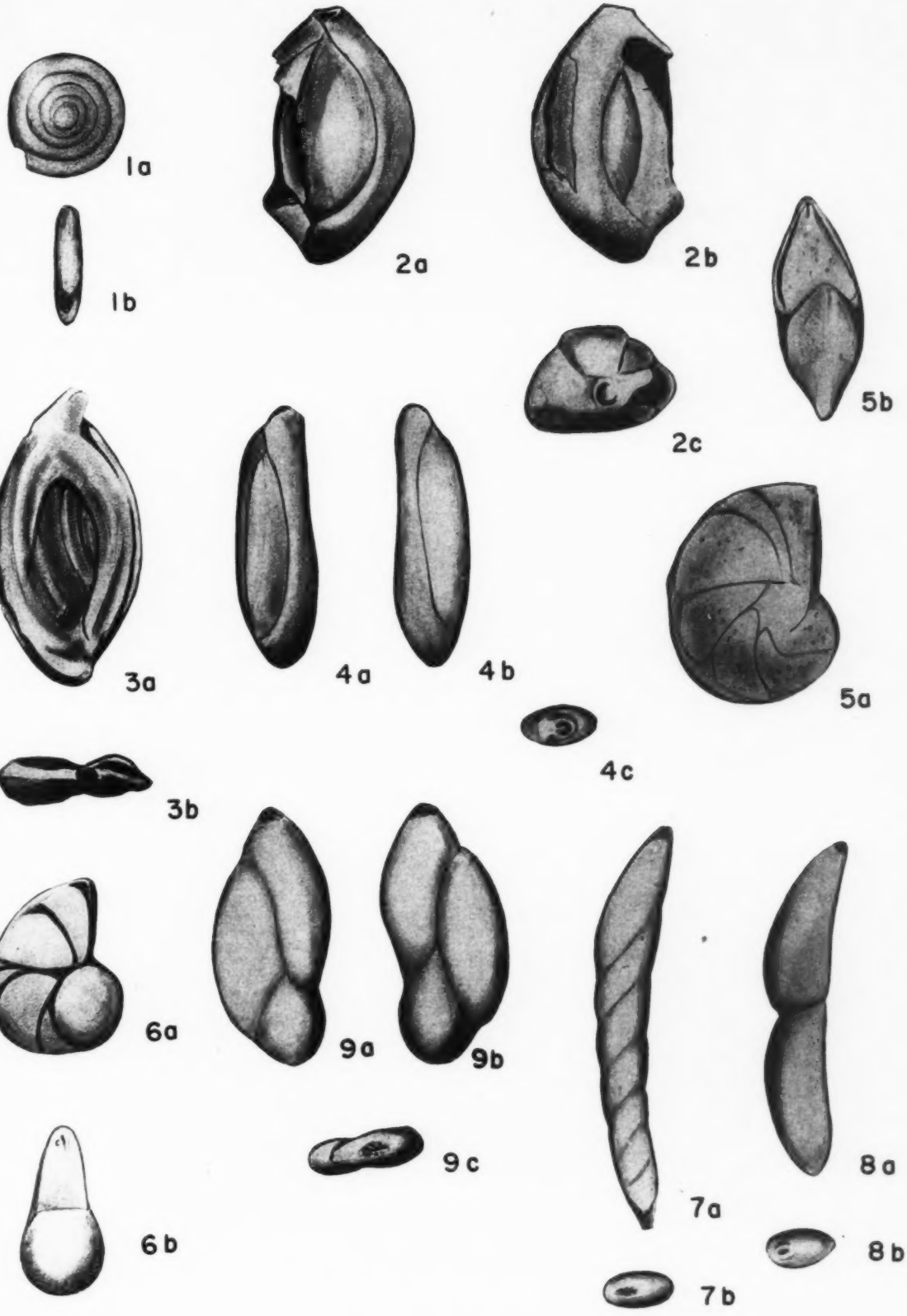
5—*Robulus* sp. *a*, Side view; *b*, apertural view; ×60; from the Upper Part, 2950–2976′ tray 1.

6—*Robulus* sp. *a*, Side view; *b*, apertural view; ×62; from the Lower Part, 2950–2976′ tray 4. This specimen is possibly a young individual of that species in fig. 5, above.

7—*Dentalina crassicauda* Seguenza. *a*, Side view; *b*, apertural view; ×58; from the Upper Part, 2950–2976′ tray 1.

8—*Dentalina* sp. *a*, Side view; *b*, apertural view; ×58; from the Upper Part, 2950–2976′ tray 1.

9—*Polymorphina acuta* d'Orbigny. *a,b*, Side views; *c*, apertural view; ×61; from the Upper Part, 2950–2976′ tray 1.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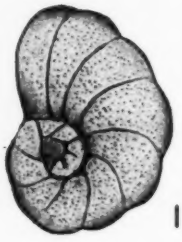
1a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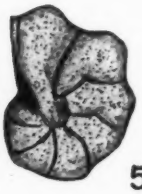
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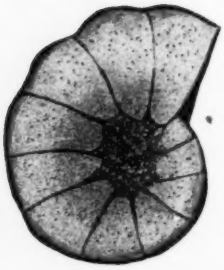
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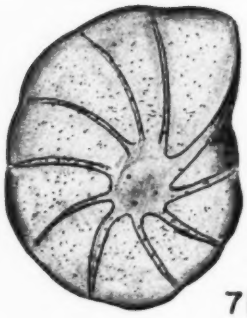
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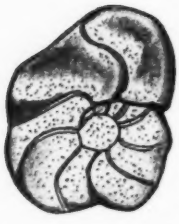
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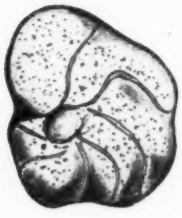
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unconformity is widespread and represents one of the major breaks in the sedimentary record in this region.

Cushman & Simonson (1944) described the Tumey foraminiferal fauna in part from the Seaboard Welsh No. 1 and relate this unconformity from outcrop in the Ciervo Hills to the west to this well.

The writer discovered the fauna in January and February 1958, in a study of some lower Tertiary foraminiferal sequences. The minute size of most of the specimens made necessary the use of a 250-mesh screen in the washing process; the washed material was treated with carbon tetrachloride to concentrate the fossils.

Acknowledgments.—Mr. L. S. Chambers, The Texas Company, Los Angeles, kindly gave permission to use and publish data from the Welsh No. 1. Appreciation is extended to the following: Mr. R. Stanley Beck, Bakersfield, for his invaluable advice and suggestions; to Drs. Robert Arnal, San Jose State College, Orville Bandy, University of Southern California, Herbert Skolnick, Western Gulf Oil Company, for their help. This paper is published by permission of Western Gulf Oil Company.

THE FAUNA

The fauna is divisible into two parts by a faunal break at 2950–2976′:

1) Upper Part, 2843′ to tray 1 of the core 2950–2976′. *Bolivina brevior* is restricted to this part.

2) Lower Part, tray 4 of the core 2950–2976′ to 3298′. *Nonion tuberculatum* is restricted to this part.

Text-figure 2, is a check-list of the fauna.

Discussion of Age.—Of the species in this fauna previously recorded in the California Miocene, two are significant in age dating: *Bolivina brevior*, the lowest occurrence of which is listed by Kleinpell (1938, Table 18) as being upper Saucesian Stage; and *Nonion tuberculatum*, restricted by Bandy & Arnal (personal communication) to the Zemorrian-lower part of Saucesian Stages.

Based on the close succession of these two non-contemporaneous species, the following age determination is presented:

1) Upper Part—upper Saucesian Stage to possibly an indeterminate younger age higher in the interval;

2) Lower Part—lower Saucesian Stage into the Zemorrian Stage. Taking into consideration the unconformity at the base of the Temblor, part of the lower Zemorrian at least should be missing. The lower limit of the part might therefore be upper Zemorrian Stage.

Nonion tuberculatum probably represents the species commonly referred to as "*Nonion* cf. *affinis*," by which workers identify the "*Nonion* cf. *affinis* Zonule," lower Zemorrian of the San Joaquin Valley. As the biostratigraphic unit *Zonule* has no vertically fixed dimensions, the Lower Part of this paper probably represents a faunule ecologically similar but younger than the lower Zemorrian-occurring "*Nonion* cf. *affinis* Zonule" (or perhaps more correctly "*Nonion tuberculatum* Zonule"), if the common presence of this species justifies any correlation at all.

EXPLANATION OF PLATE 84

FIG. *1*—*Nonionella auris* (d'Orbigny). *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×50; from the Upper Part, 2843–2881′.

2—*Nonionella* cf. *N. hummelincki* Pijpers. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×67; from the Upper Part, 2950–2976′.

3—*Nonionella limbato-striata* Cushman *evoluta* Garrison, n. var. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×68; from the Upper Part 2950–2976′.

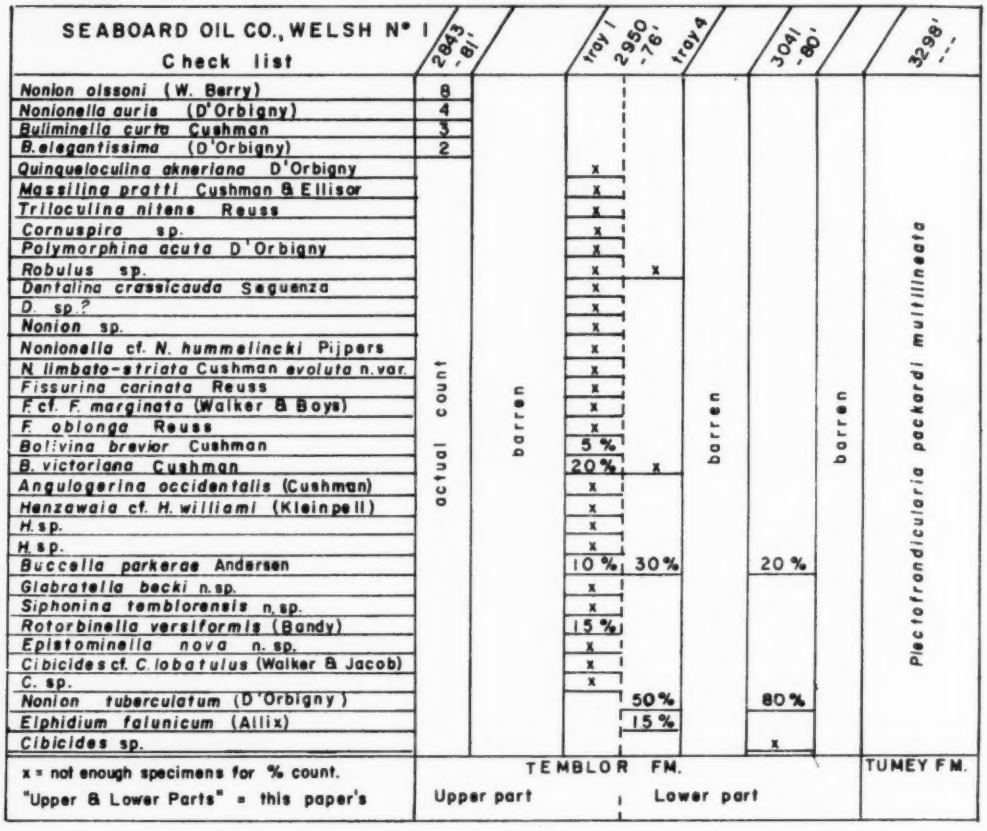
4—*Nonion olssoni* (W. Berry). *a*, Side view; *b*, apertural view; ×64; from the Upper Part, 2843–2881′.

5—*Nonion* sp. *a*, Side view; *b*, apertural view; ×95; from the Upper Part, 2950–2976′.

6—*Nonion tuberculatum* (d'Orbigny). *a*, Side view; *b*, apertural view; ×46; from the Lower Part, 3041–3080′.

7—*Elphidium falunicum* (Allix). *a*, Side view; *b*, apertural view; ×43; from the Lower Part, 2950–2976′ tray 4.

8—*Cibicides* sp. *a*, Dorsal view; *b*, ventral view; *c*, apertural view; ×76; from the Upper Part, 2950–2976′.



TEXT-FIG. 2—Check-list of the species and varieties comprising the fauna.

Nonion affinis (Reuss) does occur in the California Miocene (Kleinpell, 1938), and is restricted to lower Zemorrian.

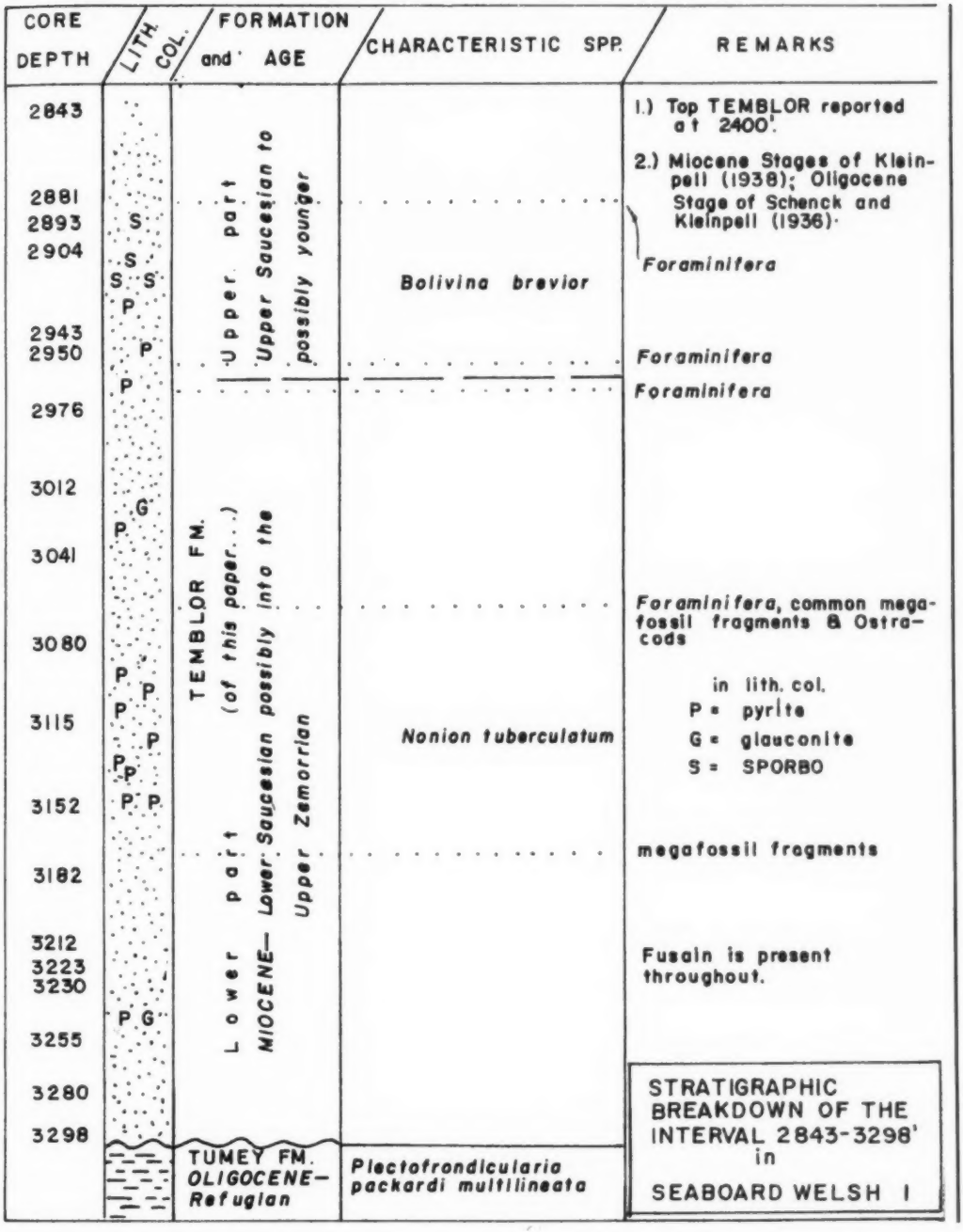
PALEOBATHYMETRY

Upper Part.—The most abundant species are *Bolivina brevior, B. victoriana, Buccella parkerae,* and *Rotorbinella versiformis.* The genus *Buccella* shows a preference for shallow waters; of the extant species in Andersen's (1952) study, all were found living in waters down to 390 feet. Bandy (1953, p. 168) found *B. mansfieldi* (morphologically close to *B. parkerae*) in his "Middle Neritic Zone," depths down to 150 feet. Walton (1955) found living *B. frigida* in depths ranging from 6 to 122 fathoms. Living *Rotorbinella versiformis* is shown by Bandy (*op. cit.*) to be restricted to the "Middle Neritic Zone."

These numerically significant species seem to be ecologically significant as well, and it is assumed that the more tolerant *Bolivina* spp. reflect the shallow environment indicated by *Buccella* and *Rotorbinella* spp., that is, depths down to approximately 200 feet.

Lower Part.—*Nonion tuberculatum, Elphidium falunicum,* and *Buccella parkerae* make up almost the entire fauna in this part.

The presence of *Nonion, Nonionella,* and *Elphidium* spp., among other things, marks Bandy's "Middle Neritic Zone," Natland's (1933, p. 227) "Zone II"—depths 14 to 125 feet, and Bandy and Arnal's (1957, p. 2040) "Inner Shelf fauna," depths to 150 feet. Norton (1930, p. 346) says that *Elphidium* " . . . seems to be a rather common genus in warm shallow waters, and some of its species are probably rather closely confined to these limits." Lowman (1949, p. 1956) includes Elphidium in a "strongly brackish and nearshore marine (inner neritic)" environment.



TEXT-FIG. 3—Stratigraphic breakdown of the 455 foot interval in the Seaboard Welsh No. 1.

TEXT-FIG. 4—*Nonion affinis* (Reuss). A side view, ×45.

The comments regarding *Buccella* in the Upper Part are also applicable here.

Conclusions.—Following Kleinpell's advice (1938, p. 82) that proportion and the overall aspect of a fauna be regarded as the most valid ecological criteria, a range of deposition down to 200 feet in depth is indicated for the entire fauna.

Effect of paleobathymetric range of age determination.—At such shallow depths of deposition, rapidly changing and non-uniform ecologic factors exercise a maximum effect on the biostratigraphic sequence. Sequences of neritic assemblages are therefore difficult to use in geologic age dating, the reasons being: 1) diversity of ecologic niches is at a maximum, 2) sedimentation passes rapidly over to erosion, resulting in hiatuses and diastems, 3) reworking is common, 4) organisms can be displaced from, or retained past, their usually accepted age limits if the ecologic niche is disrupted or prolonged.

These factors work adversely on the reliability of age indicators in neritic assemblages. The method of age determination in this paper is based on the horizon of extinction of one species being non-contemporaneous with the lowermost age limit of another.

SYSTEMATICS

Thirty-four species including one variety comprise the fauna. A number of species were so rare (sometimes only one specimen) that they were unidentifiable because the range of variation was not observed. The reference list below gives the original reference of all identified species, and the plate and figure numbers of all species in this paper, together with the horizon of occurrence. New species and the one new variety are described. Free-hand drawings are by the writer. Types are mounted and in the writer's possession.

Reference List:

Angulogerina occidentalis (Cushman), 1922, Carnegie Inst. Washington, publ. 311, p. 34, pl. 5, figs. 3,5. (This paper, Pl. 85, figs. 5a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Bolivian brevior Cushman, 1925, Contr. Cushman Lab. Foram. Res., vol. 1, p. 31, pl. 5, figs. 8a,b. (This paper, Pl. 85, figs. 3a,b. Common in Upper Part, 2950–2976′ tray 1.)

Bolivina victoriana Cushman, 1936, Sp. Publ. 6, Cushman Lab. Foram. Res., p. 55,

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EXPLANATION OF PLATE 85

FIG. 1—*Buliminella curta* Cushman. *a*, Side view; *b*, apertural view; ×55; from the Upper Part, 2843–2881′.

2—*Buliminella elegantissima* (d'Orbigny). *a*, Side view; *b*, apertural view; ×57; from the Upper Part, 2843–2881′.

3—*Bolivina brevior* Cushman. *a*, Side view; *b*, apertural view; ×75; from the Upper Part, 2950–2976′.

4—*Bolivina victoriana* Cushman. *a*, Side view; *b*, apertural view; ×75; from the Upper Part, 2950–2976′.

5—*Angulogerina occidentalis* (Cushman). *a*, Side view; *b*, apertural view; ×65; from the Upper Part, 2950–2976′.

6—*Fissurina* cf. *F. marginata* (Walker & Boys). *a*, Side view; *b*, apertural view; ×69; from the Upper Part, 2950–2976′.

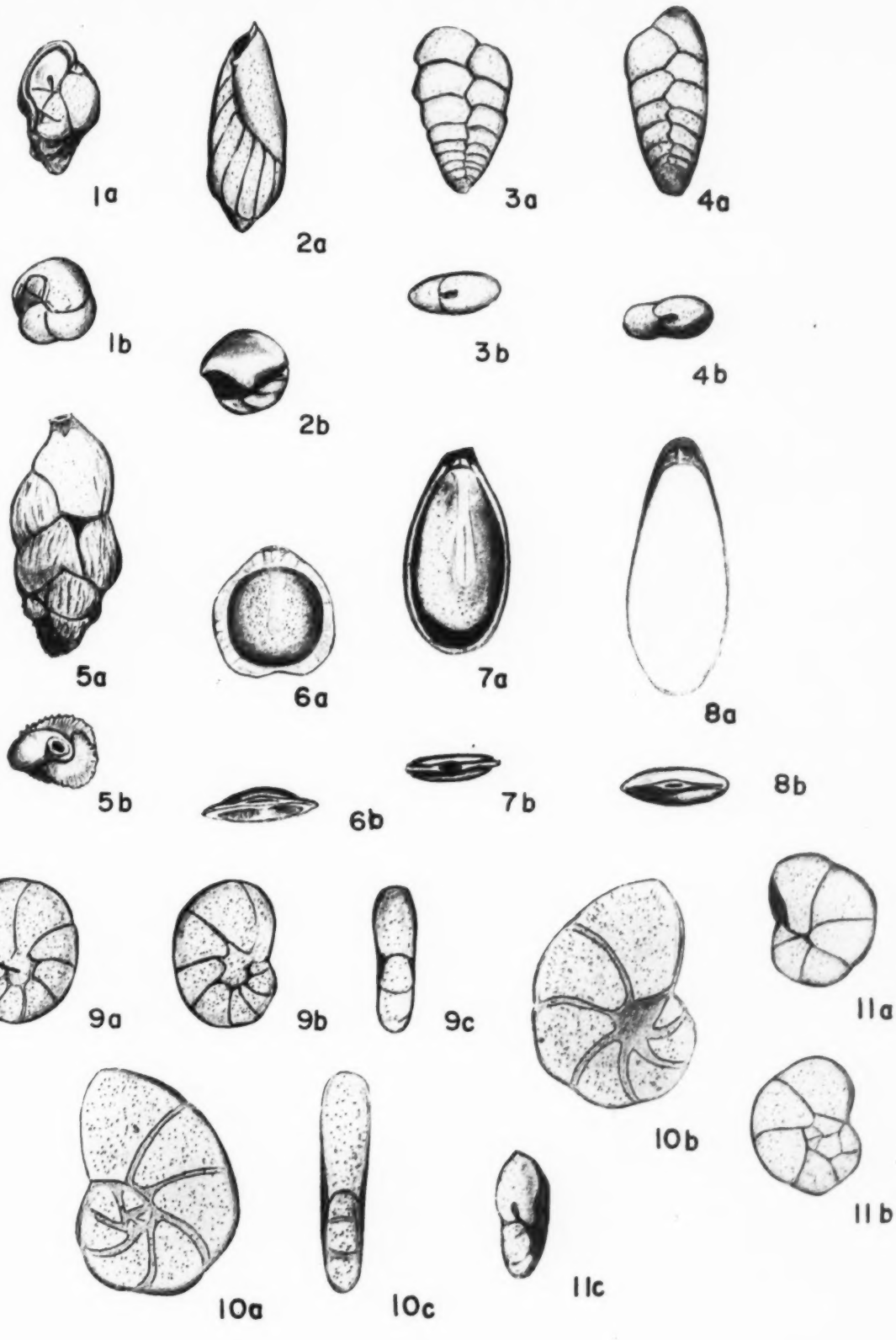
7—*Fissurina carinata* Reuss. *a*, Side view; *b*, apertural view; ×50; from the Upper Part, 2950–2976′.

8—*Fissurina oblonga* Reuss. *a*, Side view; *b*, apertural view; ×90; from the Upper Part, 2950–2976′.

9—*Hanzawaia* sp. *a,b*, Side views; *c*, apertural view; ×75; from the Upper Part, 2950–2976′.

10—*Hanzawaia* sp. *a*, Dorsal view; *b*, ventral view; *c*, apertural view; ×65; from the Upper Part, 2950–2976′.

11—*Epistominella nova* Garrison, n. sp. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×70; from the Upper Part, 2950–2976′.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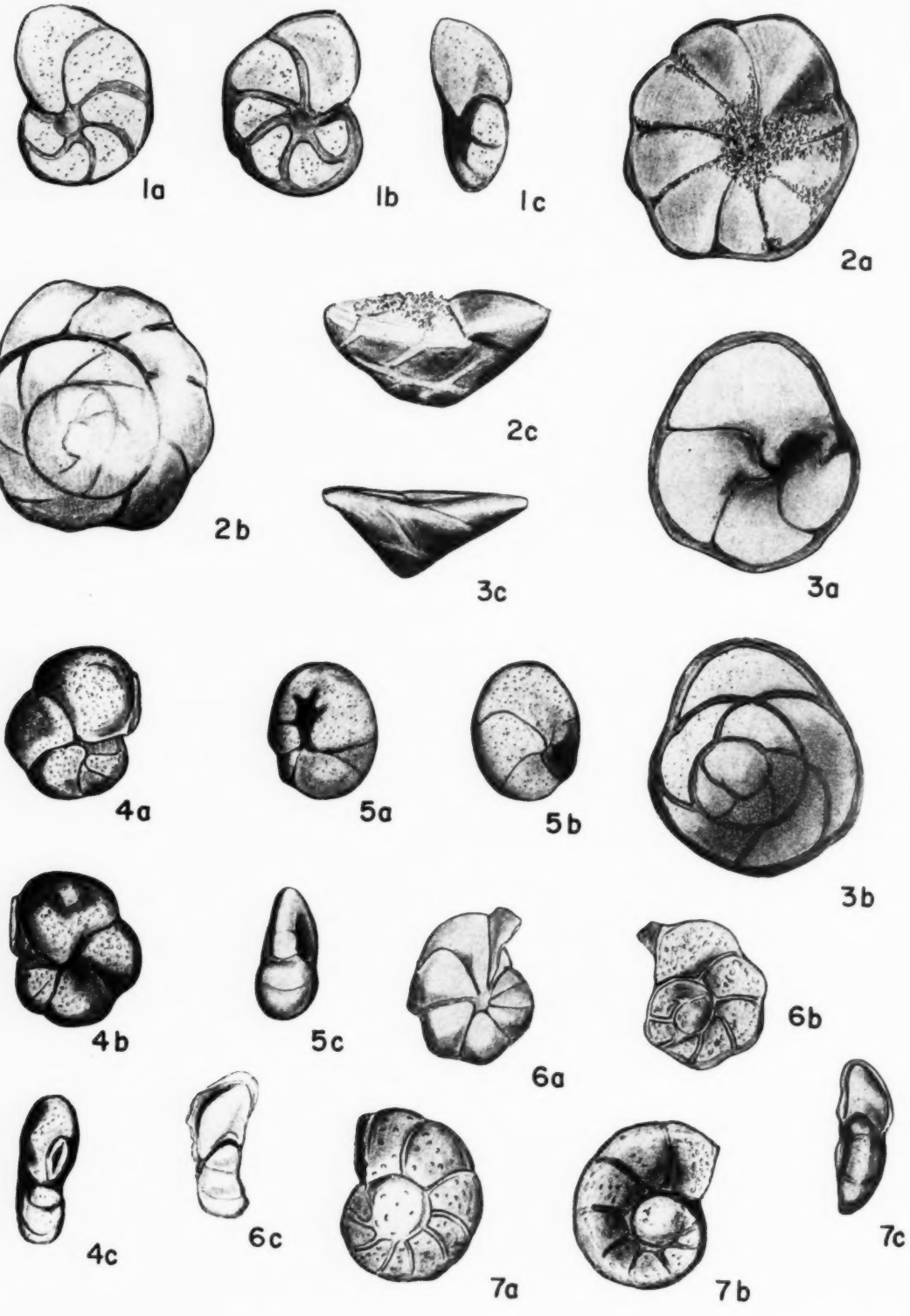
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pl. 8, figs. 2a,b. (This paper, Pl. 85, figs. 4a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Buccella parkerae Andersen, 1952, Jour. Washington Acad. Sci., vol. 42, no. 5, p. 149, pl., figs. 9a–c. (This paper, Pl. 86, figs. 2a–c. Abundant 2950–2976′ to 3041–3080′, Upper and Lower Parts.)

Buliminella curta Cushman, 1925, Contr. Cushman Lab. Foram. Res., vol. 1, p. 33, pl. 5, fig. 13. (This paper, Pl. 85, figs. 1a,b. Rare in Upper Part, 2843–2881′.)

Buliminella elegantissima (d'Orbigny). 1839. Voy. Amer. merid., vol. 5, no. 5, "Foraminiferes," p. 51, pl. 7, figs. 13,14. (This paper, Pl. 85, figs. 2a,b. Rare in Upper Part, 2843–2881′.)

Cibicides cf. *C. lobatulus* (Walker & Jacob). This paper, Pl. 86, figs. 6a–c. One small specimen in Upper Part, 2950–2976′ tray 1.)

Cibicides sp. (This paper, Pl. 84, figs. 8a–c. One specimen in Upper Part, 2950–2976′ tray 1.)

Cibicides sp. (This paper, Pl. 86, figs. 7a–c. One small specimen in Lower Part, 3041–3080′.)

Cornuspira sp. (This paper, Pl. 83, figs. 1a,b. Rare and usually broken specimens in Upper Part, 2950–2976′ tray 1.)

Dentalina crassidauda Seguenza, 1880, Le Formazioni Terziarie nella Provincia di Reggio (Calabria), R. Accad. Lincei, mem. ser. 3, vol. 6, p. 138, pl. 13, fig. 5. (This paper, Pl. 83, figs. 7a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Dentalina sp.? (This paper, Pl. 83, figs. 8a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Elphidium falunicum (Allix), 1913, Feuille des jeunes naturalistes, vol. 43, p. 45, text fig. 9. (This paper, Pl. 84, figs. 7a,b. Very common in Lower Part, 2950–2976′ tray 4.)

Epistominella nova Garrison, n. sp. (This paper, Pl. 85, figs. 11a–c. Present in Upper Part, 2950–2976′ tray 1.)

Fissurina carinata Reuss, 1863, K. Akad. Wiss. Wien. p. 338, pl. 6, fig. 83, pl. 7, fig. 86. (This paper, Pl. 85, figs. 7a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Fissurina cf. *F. marginata* (Walker & Boys). (This paper, Pl. 85, figs. 6a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Fissurina oblonga Reuss, 1863, Zeitschr. deutsch geol. ges., 1858, p. 434, pl. 7, figs. 89a,b. (This paper, Pl. 85, figs. 8a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Glabaratella becki Garrison, n. sp. (This paper, Pl. 86, figs. 5a–c, p. 11. Rare in Upper Part, 2950–2976′ tray 1.)

Hanzawaia cf. *H. williami* (Kleinpell). (This paper, Pl. 86, figs. 1a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Hanzawaia sp. (This paper, Pl. 85, figs. 9a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Hanzawaia sp. (This paper, Pl. 85, figs. 10a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Massilina pratti Cushman & Ellisor, 1931, Contr. Cushman Lab. Foram. Res., vol. 7, p. 53, pl. 7, figs. 4a–c. (This paper, Pl. 83, figs. 3a,b. Rare in Upper Part, 2950–2976′ tray 1.)

Nonion olssoni (W. Berry), 1928, Eclogae geol. Helvetiae, vol. 21, p. 403, text figs. 23a–c. (This paper, Pl. 84, figs. 4a,b. Present in Upper Part, 2843–2881′. This species is

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EXPLANATION OF PLATE 86

FIG. *1*—*Hanzawaia* cf. *H. williami* (Kleinpell). *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×61; from the Upper Part, 2950–2976′.

2—*Buccella parkerae* Andersen. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×60; from the Upper Part, 2950–2976′.

3—*Rotorbinella versiformis* (Bandy). *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×57; from the Upper Part, 2950–2976′.

4—*Siphonina temblorensis* Garrison, n. sp. *a,b*, Side views; *c*, apertural view; ×110; from the Upper Part, 2950–2976′.

5—*Glabratella becki* Garrison, n. sp. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×54, from the Upper Part, 2950–2976′.

6—*Cibicides* cf. *C. lobatulus* (Walker & Jacob). *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×65; from the Upper Part, 2950–2976′.

7—*Cibicides* sp. *a*, Ventral view; *b*, dorsal view; *c*, apertural view; ×50; from the Lower Part, 3041–3080′.

also recorded from the Tumey formation by Cushman & Simonson.)

Nonion tuberculatum (d'Orbigny), 1846, Foram. foss. bass. tert. Vienne, p. 108, pl. 5, figs. 13, 14. (This paper, Pl. 84, figs. 6a,c. Abundant in Lower Part, 2950–2976′ tray 4, to 3041–3080′.) Drs. Bandy and Arnal, as a result of comprehensive work in the San Joaquin Valley middle Tertiary, have been able to define the range of the species here called *N. tuberculatum*. Text-figure 4 is a side view of *Nonion affinis* (Reuss) from the type Oligocene of Germany (obtained through the courtesy of Mr. R. Stanley Beck). Comparison of this species to *N. tuberculatum* reveals the distinctions that obviate reference to the *Nonion* with papillate umbilicus in this paper as "*Nonion* cf. *affinis*." Refer to Boltovskoy (1958), who has recently examined the taxonomic problems arising from interpretations of Reuss' species.

Nonion sp. (This paper, Pl. 84, figs. 5a,b. One minute specimen was found in Upper Part, 2950–2976′ tray 1.)

Nonionella auris (d'Orbigny), 1839, Voy. Amer. merid., vol. 5, no. 5, "Foraminifères," p. 47, pl. 2, figs. 15–17. (This paper, Pl. 84, figs. 1a–c. Present in Upper Part, 2843–2881′.)

Nonionella cf. *N. hummelincki* Pijpers. (This paper, Pl. 84, figs. 2a–c. One specimen in Upper Part, 2950–2976′ tray 1 closely answers the definition of Pijpers' species except that this species has half the number of chambers. It might be a young individual of *N. hummelincki* but the range of variation could not be observed.)

Nonionella limbato-striata Cushman *evoluta* Garrison, n. var. (This paper, Pl. 84, figs. 3a–c. Present in Upper Part, 2950–2976′ tray 1.)

Polymorphina acuta d'Orbigny, 1852, Prodrome de pal. strat. univ. anim. moll. ray., vol. 3, p. 160. (This paper, Pl. 83, figs. 9a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Quinqueloculina akneriana d'Orbigny, 1846, Foram. foss. bass. tert. Vienne, p. 290, pl. 18, figs. 16–21. (This paper, Pl. 83, figs. 2a–c. One broken specimen in the Upper Part, 2950–2976′ tray 1.)

Robulus sp. (This paper, Pl. 83, figs. 5a,b,6a,b. Two specimens of probably the same indeterminate species at 2950–2976 tray 1 & 4. The large individual (fig. 5, Upper Part) shows development of pores. The small individual (fig. 6, Lower Part) might be a young specimen of the species.)

Rotorbinella versiformis (Bandy), 1953, Jour. Paleontology, vol. 27, p. 179, pl. 22, figs. 5a–c. (This paper, Pl. 86, figs. 3a–c. Very common in Upper Part, 2950–2976′ tray 1.)

Siphonina temblorensis Garrison, n. sp. (This paper, Pl. 86, figs. 4a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Triloculina nitens Reuss, 1850, K. Akad. Wiss. Wien, p. 383, pl. 49, fig. 10. (This paper, Pl. 83, figs. 4a–c. Rare in Upper Part, 2950–2976′ tray 1.)

Descriptions of three new species and one new variety:

Family NONIONIDAE
Genus NONIONELLA Cushman, 1926
NONIONELLA LIMBATO-STRIATA Cushman
EVOLUTA Garrison, n. var.
Pl. 84, figs. 3a–c

Variety differing from Cushman's species from the Pliocene of the Fiji Islands (Contr. Cushman Lab. Foram. Res., vol. 7, p. 30, pl. 4, figs. 8a–c, 1931) in being evolute on the ventral side.

Dimensions: Greatest diameter 0.19 mm., thickness 0.05 mm.

Present at 2950–2976′ tray 1, where the horizon is determined as upper Saucesian Stage.

Family ROTALIIDAE
Genus GLABRATELLA Doreen, 1948
GLABRATELLA BECKI Garrison, n. sp.
Pl. 86, figs. 5a–c

The test is biconvex, minute, with a low trochoid spire. It is ovate in side view; the periphery is rounded; the ventral and dorsal sides are distinctly perforate, the perforations somewhat obscure the dorsal sutures; the chambers are few, about 4 in number and are somewhat irregular in arrangement, the amount of inflation, and the size-increase; the sutures are slightly depressed and curved; the aperture is an opening in a depression in the center of the ventral face. Fine lines radiate outward from this depression.

Dimensions of holotype: Greatest diameter, 0.12 mm., thickness 0.05 mm.

Present at 2950–2976′ tray 1, where the

horizon is determined as upper Saucesian Stage.

Genus SIPHONINA Reuss, 1850
SIPHONINA TEMBLORENSIS Garrison, n. sp.
Pl. 86, figs. 4a–c

The test is biconvex, minute, and ovate in side view; the periphery is broadly rounded; it is nearly involute on both sides; the test is conspicuously perforate with rather large foramina, but smooth; the chambers are about 5 in number, are slightly inflated, and increase gradually in size; the sutures are depressed and curved; the aperture is an elliptical opening developed on a short neck on the face of the last-formed chamber.

Dimensions of holotype: Greatest diameter 0.19 mm., thickness 0.05 mm.

Present at 2950–2976′ tray 1, where the horizon is determined as upper Saucesian Stage.

Family CASSIDULINIDAE
Genus EPISTOMINELLA Husezima & Maruhasi, 1944
EPISTOMINELLA NOVA Garrison, n. sp.
Pl. 85, figs. 11a–c

The test is minute, biconvex, and ovate in side view; the periphery is broadly rounded; the sides are rather flat and parallel; it is distinctly perforate; evolute dorsally and involute ventrally; the chambers are few, there are about 6 in number and they are not inflated; they increase gradually in size; the sutures are slightly depressed and curved; the aperture is an elongate elliptical slit in the face of the last-formed chamber, parallel to the plane of coiling.

Dimensions of holotype: Greatest diameter 0.15 mm., thickness 0.06 mm.

Present at 2950–2976′ tray 1, where the horizon is determined as upper Saucesian Stage.

SUMMARY AND CONCLUSIONS

The fauna herein described and figured occupies a 455-foot interval in the Miocene Temblor formation, separated from the underlying Oligocene Tumey formation by an unconformity.

Approximately 400 feet of Temblor formation overlie the interval containing this fauna, so it might be said that the lower half of the Temblor in this well is the age suggested by the fauna, i.e., upper Saucesian Stage to possible upper Zemorrian Stage.

The bathymetric range of deposition is neritic.

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TYPE SPECIES OF *PARAPARCHITES* ULRICH & BASSLER

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ABSTRACT—The type and cotypes of *Paraparchites humerosus* are described and figured. The original figures were based on unrecognized nested molts. The hinge is shown to be fairly simple. A velate structure along the ventral margin as indicated in the original illustration is shown to be nonexistent. A new family Paraparchitidae and superfamily Paraparchitacea are proposed to include certain paleocope ostracodes.

AMERICAN workers have described numerous species of *Paraparchites* since 1906. Kellett (1933) redescribed *P. humerosus*, the type species, and figured several instars.

While working on the Treatise on Invertebrate Paleontology (Ostracoda) one group of workers considered the original figures to be velate and therefore to be related to certain early Paleozoic forms. This resulted in a restudy of the type material made possible by a grant from the University of Illinois, Research Board. Through the courtesy of the National Museum cotypes No. 35627 were made available for study.

The original description of *P. humerosus* (1906) follows:

> "Length of large example, 1.8 mm.; height of same, 1.25 mm.; thickness of same, 1.05 mm. Carapace subovate, with the outline slightly angulated in the antero-dorsal region; surface rather strongly convex, with greatest thickness near middle of valves. Left valve with the dorsal edge straighter than in right valve, the edge in the latter being convex in outline and thickened so that it projects above the hinge line of the left valve. Ventral edge of carapace thick and slightly channeled on each side of the constant line between the valves."

To the above original description Kellett (1933 pp. 64–65) adds the following comments concerning *P. humerosus:*

> "The ventral edges are not channeled . . . , but are smooth except for the rather narrow but distinct overlap of the right valve on the left. This overlap is accomplished by means of the beveling on the inside edge of the margin of the right valve, keeping the surfaces of the valves almost flush at their juncture. Although differing from the type of *P. humerosus* in this possibly important characteristic, it would seem that these specimens belong to the species *P. humerosus*, the type very likely being weathered . . . ."
>
> "The statement in the original description of the species that the right valve is more thickened at the hinge than the left is clearly a slip of the pen, because in the description of the genus which has as its genotype *P. humerosus*, the following contrary statement is made: [dorsal edges of valves usually unequal, the left slightly more prominent and commonly overlapping the right or receiving its edge in a shallow groove.] The left valves of the specimens that I examined are all thicker and higher at the dorsum than the right valves. No hinge structure could be found on the specimens examined."

An examination of the cotypes indicates that certain features differ so greatly from the original drawings that redescription and new illustrations are warranted.

On the slide labeled "cotypes-35627" of the National Museum there are four specimens in a vertical row labeled "*Paraparchites humerosus*, Ulrich & Bassler, Carboniferous (Elmdale), Manhattan, Kansas." The four specimens are here considered from the top down as a, b, c, d.

In addition to the original slide, I. G. Sohn sent to me three slides containing paratype material labeled *P. humerosus* Ulrich & Bassler. One slide is labeled U.S.N.M. 35657. Some of the specimens are single valves, others are "nested," and others are double valves. Two of the whole carapaces are illustrated in dorsal view, Plate 87, figs. 6,7.

Specimen A.—This specimen (Pl. 87, fig. 1) consists of two right valves, the adult and the adult-minus-one molt. The molt is tilted

so that the posterior end is slightly lower than the anterior, leaving the anterior end raised above the level of the adult shell. The raised edge of the anterior cardinal corner of the adult shell and the oblique position of the molt produces a triangular space between the two valves.

The hinge of the right valve consists of a narrow edge without ornamentation or denticulation of any sort. In dorsal view the hinge contact is below a gently sloping shell surface that rises above it.

The free margin consists of a simple selvage ridge extending along all the free margin. A flat, fairly broad surface slopes gently from the selvage edge outward, this surface representing the contact zone with that portion of the left valve which overlaps the right.

In the adult a slight vestibule appears to be present inside the thickened edge of the free margin; at least, there is a recess. A similar vestibule is absent to faintly developed in the adjacent molt.

When Ulrich & Bassler speak of such internal characters as "right valve exhibiting dorsal prominence" or the presence of a "linear socket for reception of corresponding position of left valve" it must be remembered that they were looking at "nested valves." "Nesting" has been reported by a few workers and is generally attributed to mechanical causes. This phenomenon needs further study.

Specimen B.—Specimen "B" (Pl. 87, figs. 3,4) is a complete carapace. The two valves are pulled slightly apart along the ventral margin, resulting in a groove at the point of contact but the original overlap zone can be clearly seen as a darker band on each valve. Apparently specimen "B" represents the source of figures 1,2, and 3, plate 11 of Ulrich & Bassler, 1906; the end view, figure 2, and the ventral view, figure 3, show two dashed lateral lines. These lines are not ridges but presumably are an artist's interpretation of discoloration which marks the normal overlap zone. The two valves have been slightly pulled apart, leaving a gap along the contact line; the space is filled with rock material. Greatest thickness is slightly posterior of the middle. The dorsal margin is somewhat indistinct and the hinge contact cannot be observed.

Specimen C.—Specimen "C" (Pl. 87, fig. 2) consists of three right valves; an adult, an adult-minus-one, and an adult-minus-two molts. The two molts are fused in part along the hinge. The molts are completely fused in the antero-dorsal area so that both have a common edge. The two valves are also fused in the postero-dorsal area; however, two edges may be recognized. Along the hinge, near the anterior cardinal point, the large molt is raised to form a triangular cavity above the contact of the smaller molt. It is this cavity that apparently was pictured by Ulrich & Bassler along the hinge of their figure 4 and which has been subsequently copied as illustrative of this genus. The true hinge is a simple edge without grooving or ridges as described under "A" above. The larger of the two molts breaks away from the anterior end of the smaller molt and is for the most part hidden except where its edge emerges near the medial portion of the posterior end. The adult valve is similar in all respects to the one described in "A" above. It should be called to attention that the triangular opening between the two molts is similar in both specimens "A" (Pl. 87, fig. 1) and "C" (Pl. 87, fig. 2). This triangular opening originally pictured as a hinge structure is the space between two molts and has nothing to do with hinge structure.

The anterior of the molts is similar to the molt in specimen "A" and again the adult shows evidence of a slight vestibule (Pl. 87, fig. 2).

Specimen D.—On first observation specimen "D" (Pl. 87, fig. 5) would appear to be a single right valve with a marginal groove around the entire carapace. However, upon closer examination it becomes evident that the specimen consists of two right valves, both of which are molts. According to the size range these two molts should be the adult-minus-three and the adult-minus-four stages. The smaller molt is perfectly oriented with the larger. The hinge edges are parallel but are not fused. Due to this perfect orientation, a continuous channel formed by the space between the two valves

exists all the way around the contact of the two molts. The hinge edge is thin and is continuous with the selvage edge of the free margin. In the smaller molt there is preserved at the anterior cardinal corner a slight ventral extension forming somewhat of an indistinct shelf against which the left valve may have rested.

One of the striking features of the molts is the thin edge of the free margin. Thickening is present in the adult-minus-one molt but reaches its maximum in the adult. The free edge of the right valve in the molts is a simple thin edge; thickening to form an inner and outer slope from the selvage edge is an adult feature in this species. Also, this explains why the adult has a narrow recess or vestibule around the inner portion of the free margin and molts do not.

Dorsal View.—Two dorsal views are shown, one of an adult (Pl. 87, fig. 6), and one of an adult-minus-two molt (Pl. 87, fig. 7). In each specimen the smaller right valve is slightly crushed into the larger left, thus exaggerating the overlap around the ends. The greatest width is distinctly closer to one end in the adult, but only slightly so in the molt. The hinge contact lies in a distinct elongated hinge channel. In the molt the sides of the channel are about equally inclined and about *equally raised*: one valve does not overreach the other noticeably. In the adult the left valve slightly overreaches the right. Other specimens show no overreach, the dorsal surface of each valve being of equal height above the hinge. Overreach by one valve along the dorsum is not a conspicuous feature in any of the cotypes, but can be recognized in some of the adults.

ORIENTATION

Some contradictory statements concerning orientation and overlap occur in the original description. On a small card associated with the cotypes occurs the following statement: "right v. overlaps on dorsum, left valve on ventral edge"; On the opposite side of the card is written, "right overlaps on dorsum, left valve on ventral side." The author of the written comments on the card is unknown. Kellett (1933, p. 65) noted discrepancies in the original description and considered the left valve as over-reaching the right along the dorsum and the right valve as overlapping the left along the free margin. Geis (1932) questioned the orientation which made the right valve overlap the left along the free margin but did not change it.

Kesling (1958, pp. 192–193) has reviewed the conflicting statements by Ulrich & Bassler (1906) concerning overlap and orientation. He concludes that the right valve overlaps the free margin of the left.

The orientation favored here is the opposite to that proposed by Kellett (1933) and Kesling (1958) and followed in part by Copper (1941, 1946). In this paper the orientation is based on a combination of several features. The end possessing the greatest height is considered anterior. In this instance the "swing" is forward, the thickest end is posterior, spines when present are posterodorsal, and the faint muscle scar, rarely preserved, is anterior. This results in the left valve overlapping the right along the free margin, and right valve slightly overreaching the left (in adults) along a portion of the dorsum. This orientation has the advantage of bringing into harmony several morphological features as well as maintaining harmony between genera such as *Paraparchites* and *Pseudoparaparchites*. Also, in the instar sequence as pictured by Kellett (1933, pl. 13) the most truncated or pointed end of the early molts is posterior, a feature observed in many ostracodes.

Although the greatest width has been often referred to as "medial," it is in fact near one end of the carapace in a great majority of specimens. In a sequence of molts shown in dorsal view by Kellett (1933, pl. 13, figs. 8–12) the thickest end is distinctly left (posterior). In lateral view the early molts are considerably higher in the stable anterior half of the carapace than in the posterior half.

CLASSIFICATION

It appears that the Late Paleozoic *Paraparchites* are not closely related to *Aparchites*. *Paraparchites* and related genera are nonvelate and nonsulcate. Also, the valves are unequal in size, usually with pronounced overlap around the free margin and the hinge is channelled. A new family is here

proposed to receive *Paraparchites* and related genera, *Pseudoparaparchites*, *Proparaparchites*, and *Microcoelonella*.

Coelonella Stewart, from the Middle Devonian, is considered a synonym of *Paraparchites*. *Microcoelonella* Coryell & Sohn is very similar to *Paraparchites* and upon further study may prove to be a synonym. *P. scapha* (Stewart) and *P. plana* (Stewart) are here oriented with the left valve overlapping the right and the greatest height in the anterior half.

Kesling (1958) identifies certain Devonian specimens as *Antiparaparchites* and recognizes *Antiparaparchites* Coryell & Rogatz (1932) as a valid genus. In this paper *Antiparaparchites* is considered a synonym of *Paraparchites*.

Antiparaparchites primaevus Kesling with its short hinge, sharp and distinct flexure at each end of the hinge, strongly truncated postero-dorsal margin and its form ratio of approximately .86 indicates that it probably is not related to *Paraparchites*. The form ratio of *P. humerosus* is approximately .65 giving it an elongated shape compared to the more round outline of *A. primaevus*.

Many species possessing a strongly truncated posteroventral margin have been referred to *Paraparchites*. Because these do not conform in outline to the genotype they will be placed in one or more new genera in a future paper.

Superfamily PARAPARCHITACEA Scott, n. superfam.

Nonsulcate, nonlobate, nonvelate paleocopes with unequal valves, the larger overlapping the smaller around all or most of the free margin.

PARAPARCHITIDAE Scott, n. fam.

Nonsulcate, nonlobate, nonvelate, smooth to punctate ostracodes with posterodorsal spines sometimes present; the dorsum is straight to gently convex; the valves are unequal with the larger valve overlapping the smaller one along the free margin, the valves are subovate to elongate-ovate with the ends broadly rounded; the hinge commissure is straight or interrupted at ends by faint to moderately strong posterior and anterior cardinal indentations where the overlap begins; one valve may slightly overreach the other dorsally, but dorsal shoulders usually are of equal height; Dev.-Permian.

PARAPARCHITES Ulrich & Bassler, 1906.
[*P. humerosus*] [= *Antiparaparchites* Coryell & Rogatz, 1932] [= *Coelonella* Stewart, 1936]
Pseudoparaparchites Kellett, 1933.
[*P. kansensis*]? [= *Microparaparchites* Croneis and Gale, 1938]
Proparaparchites Cooper, 1941.
[*P. ovatus*]
Microcoelonella Coryell & Sohn, 1938.
[*M. scanta*]

Revised generic description.
PARAPARCHITES Ulrich & Bassler, 1906

Type species: *Paraparchites humerosus* Ulrich & Bassler, 1906. New American Paleozoic Ostracoda. Proc. U. S. Nat. Mus. v. 30, pp. 149–151, pl. 11, figs. 1–4.

Ovate to elongate-ovate ostracodes; the ends are broadly rounded; the dorsum in lateral view is usually straight but is occasionally gently convex; the hinge channel is strong; the valves asymmetrical, the larger overlaps the free margin of the smaller, reversal of overlap is known; the dorsal umbonal area of each valve is raised to about the same height, but one umbonal area may slightly overreach the other in some species; the inner free margin of the smaller valve (usually the right) consists of a simple selvage ridge with an outer and inner selvage slope; the hinge is simple; dimorphism is unknown.

PARAPARCHITES HUMEROSUS Ulrich & Bassler, 1906
Pl. 87, figs. 1–7

There are four specimens on the U. S. National Museum slide numbered 35627. These are described above as "A, B, C, and D." The complete carapace, specimen "B," is figured on Plate 87, figs. 3,4. It is selected as the *Lectotype*. Specimens "A, C, and D," Plate 87, figs. 1,2,5, are "nested" *paratypes*. Specimens represented by Plate 87, figs. 6 and 7 carry U. S. Nat. Museum numbers 137564a and 137564b and are considered *paratypes*.

	Length mm.	Height mm.	Width mm.
Fig. 1—Adult	2.0	1.3	
Adult-minus one instar	1.7	1.3	
2—Adult	1.9	1.26	
Adult-minus one instar	1.7	1.1	
Adult-minus two instar	1.6	0.96	
3,4 Adult	1.9	1.3	1.0
5—Adult-minus two instar	1.6	1.0	
Adult-minus three instar	1.4	0.9	
6—Adult-minus three instar, anterior left	1.4	0.9	0.7
7—Adult-minus one instar, dorsal anterior left	1.8	1.2	0.8

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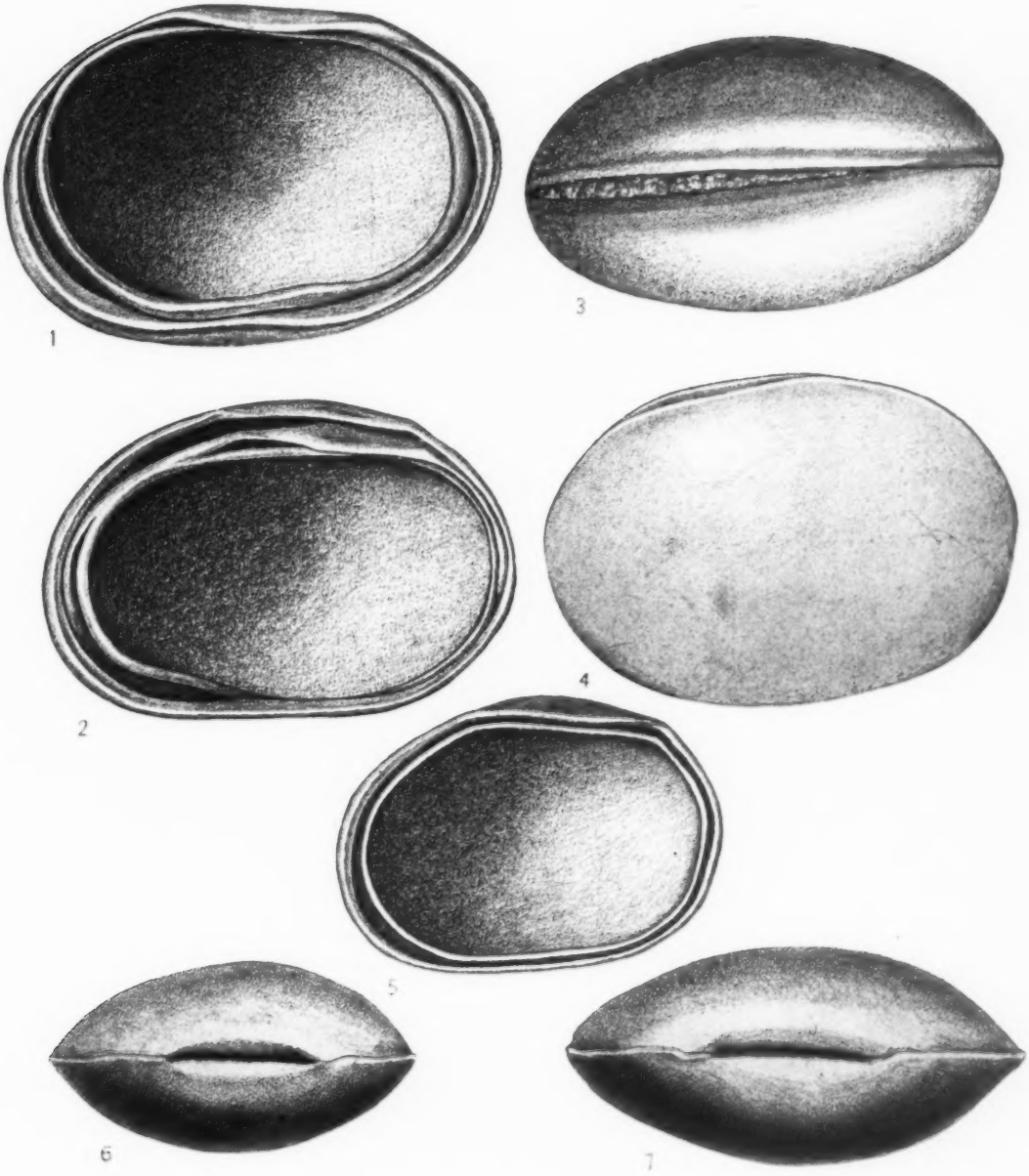
EXPLANATION OF PLATE 87
all figures × 32.

FIGS. *1-7*—*Paraparchites humerosus* Ulrich & Bassler 3–4, Lectotype, U. S. Nat. Mus. 35627. Venter and right valve slightly tilted to show hinge channel. *1*, Right valves, adult and adult-minus one instar. *2*, Right valves, adult, adult-minus one and minus two instars. *5*, Right valves, adult-minus two and minus three instars. *6*, Dorsum, adult minus three instar, paratype, U. S. Nat. Mus. 137564a. *7*, Dorsum, adult-minus one instar, paratype, U. S. Nat. Mus. 137564b.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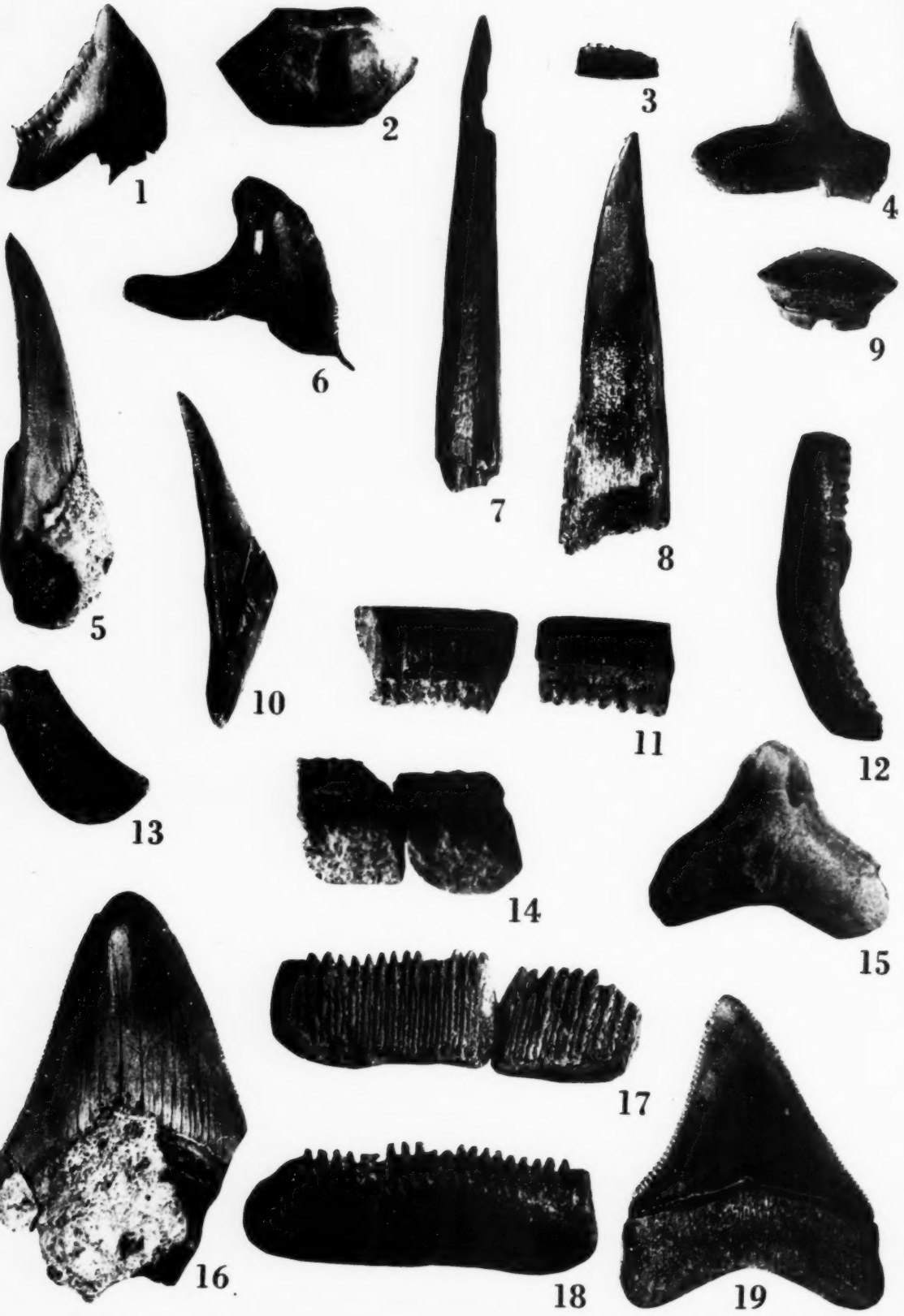
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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 675–679, PL. 88, 1 TEXT-FIG., JULY 1959

SOME FOSSIL FISH TEETH FROM TERTIARY DEPOSITS OF MAYURBHANJ, INDIA

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ABSTRACT—Nine species of fish teeth from limestone and clay of questionable lower Miocene age are described. Two new varieties *Aetobatis arcuatus* var. *baripadensis* and *Hypolophus sylvestris* var. *mohuliyi* are proposed. The age of the containing beds is discussed.

INTRODUCTION

IN JANUARY 1956, field investigation was conducted to study the Tertiary sediments of Mayurbhanj around the town Baripada (Lat. 22° 54′: Long. 86° 44′). During the field work several shark teeth were obtained from an arenaceous limestone bed. This bed is exposed on the left bank of the river Burhabalang west of Usurdihi, a small village 2 miles south of the town Baripada. The location of this fossiliferous bed was reported earlier by P. N. Bose (1904).

The bed which yielded the fossils is composed of a yellowish brown arenaceous limestone, interbedded with bands and lenses of greenish clay. Fossils were found both in clay and limestone. The age of this bed has been provisionally assigned by Eames (1936) to be lower Miocene, on the basis of the presence of *Ostraea gajensis*.

SYSTEMATIC PALAEONTOLOGY

Subclass ELASMOBRANCHII
Order SELACHII
Suborder GALEOIDEA
Family ISURIDAE (LAMNIDAE)
Genus CARCHARODON Muller & Henle
CARCHARODON MEGALODON Agassiz, 1843
Pl. 88, figs. 10,19

Material.—One isolated tooth.

Description.—The tooth is broad, flat, and not especially thick. The height of the coronal surface is more than the breadth. The outer surface is flat, the inner one slightly concave up to ⅔ from the base; then it abruptly becomes convex towards the tip. The tip is deflected slightly outwards. The cutting edge is serrated; the serrations are uniform throughout. The enamelled surface is longitudinally striated and cracked. There is a narrow ridge in the middle of the outer

EXPLANATION OF PLATE 88

FIGS. *1,6—Hemipristes serra* Agassiz. Anterior views, ×2 and ×3 respectively.
2,9—Hypolophus sylvestris mohuliyi Ghosh, n. var. *2*, Basal view, showing strong medial groove, ×5; *9*, front view, ×4.
3—Myliobatis sp. A fragment of a spine, ×2.
4—Carcharhinus (*Aprionodon*) *frequens* Dames. View showing median sulcus, ×6.
5,16—Cacharodon megalodon robutus Davies. *5*, Side view, ×1¼; *16*, anterior view, ×1¼.
7,8—Pristes aquitanicus Delfortrie. Posterior and top views, both ×1⅓.
10,19—Cacharodon mecalodon Agassiz. Side and anterior views, both ×1⅓.
11—Rhinoptera raeburni White. Two separate specimens showing vermiculating ridges, both ×2.
12,17,18—Aetobaties arcuatus baripadensis Ghosh, n. var. *12*, Side view, ×1⅔; *17*, specimen showing birfurcation of the basal ridges, ×2½; *18*, coronal view of specimen, ×2.
13,15—Carcharhinus (*Prionodon*) *egertoni* Agassiz. Anterior views, ×2½ and 3, respectively.
14—Rhinoptera sherborni White. Side view, ×4.

coronal surface. Both the cutting edges are convex but one is more so than the other. The root is bifurcated and does not extend laterally beyond the enamelled surface. The lower margin is broadly angular and is nearly parallel to the lower margin of the anterior enamelled surface. The margin of the posterior enamelled surface is more sharply angular and a crescentic area is without enamel between the upper margin of the root and lower margin of the enamel. The anterior surface of the root is flat but the posterior surface has a bulbous enlargement in the middle. The lateral denticles are absent.

Measurements.—Height, 42.5 mm.; breadth, 36.5 mm.; thickness, 10.5 mm.

CARCHARODON MEGALODON ROBUSTUS
Davis, 1888
Pl. 88, figs. 5,16

Material.—One isolated tooth; the lateral edge of the root and part of the enamel is missing.

Description.—The tooth is higher than wide, is moderately thick, and is more or less symmetrical. The outer coronal surface is slightly concave; the inner one is convex, both laterally and vertically. The cutting edges are uniformly serrated; one edge is slightly concave, another slightly convex. The lower median portion of the outer coronal surface is depressed with a narrow ridge at the center extending from the base of the enamelled surface to the tip. The enamelled surface is cracked, giving a striated appearance. The root is bifurcate. The height of the root is approximately $\frac{1}{4}$ the height of the enamelled surface. The lower margin of the root is broadly angular and is nearly parallel with the lower margin of the enamelled surface. On the inner coronal surface there is a crescentic unenamelled area above the upper margin of the root. This portion is ornamented by elliptical patterns that have their major axes parallel to the axis of the tooth. The inner surface of the root is laterally convex and there is a corresponding concavity in the outer surface.

Measurements.—Height, 42.5 mm.; breadth, 36.5 mm.; thickness, 10.5 mm.

Discussion.—This variety and *Carcharodon megalodon* s.s. have been shown to be synonymous by Woodward (1889), but White (1926) has referred it to the variety *robustus*. The author has followed White after noting significant differences between the two.

Family GALEOLAMNIDAE (CARCHARINIDAE)
Genus CARCHARHINUS Berg, 1943
Subgenus PRIONODON
CARCHARHINUS (PRIONODON) EGERTONI
Agassiz, 1847
Pl. 88, figs. 13,15

Material.—Two imperfect isolated teeth. The tips of the teeth are broken.

Description.—For one tooth (Pl. 88, fig. 13), the height and breadth are the same. The enamelled surface is quite smooth and there is one low ridge in the middle that does not extend to the tip. The lateral margins are uniformly concave towards the tip and are finely serrated. The serrations are weak. The lower margin of the enamel is broadly crescentic. The root is not well preserved. As one side of the specimen is broken, the interior is visible. It is hollow.

The second specimen is similar to the one just described with few differences. The lateral margins are angularly concave, the serrations are present only near the base, the outer coronal surface is more or less flat, and the inner surface is convex. The root is fairly thick and does not extend laterally much beyond the enamelled surface. The lower margin of the root is angularly crescentic.

Measurements.—(Second specimen): Height, 12 mm.; breadth, 12 mm.; thickness, 3 mm.

Discussion.—The second specimen has some similarity with *P. aculeatus* Davis, but it is relatively more acute and the serrations are comparatively stronger.

Subgenus APRIONODON Gill
CARCHARHINUS (APRIONODON) FREQUENS
Dames, 1883
Pl. 88, fig. 4

Material.—One isolated tooth.

Description.—The tooth is very small and triangular. The enamelled surface is smooth. The cutting edges are smooth and entire. The outer coronal surface is flat, the inner one convex laterally. The tip is pointed and deflected inwards; the outline tends to be sigmoidal. The tooth is situated on the anterior side of the root. The root is thick; the outer surface is more or less flat; the inner surface is strongly convex. There is a nutri-

tive sulcus in the middle. The branches of the root expand horizontally, meeting at an angle of approximately 180°. The lateral end of the root is thin and rounded. The height of the root is more than half that of the enamelled surface; the length is more than the height.

Measurements.—Height, 12 mm.; breadth, 12 mm.; thickness, 3 mm.

Discussion.—The specimen has some similarity with the lateral tooth of *Carcharhinus egertoni* Agassiz, as is evident from the specimen figured by Leriche (1942), but the greater length of the root compared to the height of the enamelled surface establishes its identity with the above species.

Genus: HEMIPRISTES
HEMIPRISTES SERRA Agassiz
Pl. 88, figs. 1,6

Material.—Two isolated teeth.

Description.—This species has been reported earlier from the same area by Modak (1951). The tooth is triangular and smooth, is very much asymmetrical, and is laterally convex. The cutting edges are thin and strongly and coarsely serrated. The serrations increase in size towards the tip but end a few mm. from it. The tip is acutely pointed. One of the cutting edges is strongly convex and the other concave. The root is thick; the two branches meet at an angle. The lower margin of the enamelled surface forms an angle in the middle more acute than that formed by the branches of the root.

Order BATOIDEA
Family PRISTIDAE
Genus PRISTES Latham
PRISTES AQUITANICUS Delfortrie
Pl. 88, figs. 7,8

Material.—One isolated rostral tooth.

Description.—The tooth is long and the surface is more or less smooth with faint noncontinuous striations. The anterior surface gently tapers toward the tip, with gradual increase in curvature. The posterior surface is straight and has a broad sulcus. The concavity of the sulcus diminishes toward the tip and the surface becomes flat a few mm. from the tip. The dorsal surface is flatter than the ventral one. The basal portion is broken. It appears that it was firmly implanted in socket. There is a variation in color, the tooth being brownish black toward the tip and yellowish brown toward the base.

Measurements.—Length (observed), 3 cm.

Discussion.—The specimen has some similarity with *P. bisulcatus* Agassiz and *P. lathami* Galeoti. It is difficult to identify specifically on the basis of the rostral tooth alone. However, the relatively broad sulcus and gradual slope of the tooth toward the tip indicates its reference to *P. aquitanicus.*

Family MYLIOBATIDAE
Genus MYLIOBATIS Cuvier, 1817
MYLIOBATIS sp.
Pl. 88, fig. 3

Material.—Fragment of a spine.

Description.—The surface is glossy and longitudinally striated. The striations are in places anastomosing and wavy. The cross-section is elliptical. The serrations are lateral. The lip of the serrations points anteriorly. The posterior of individual denticles is convex. The anterior is straight imparting a sawtooth character.

Discussion.—Different specific names have been given to *Myliobatis* spine fragments by different authors but the specific identification seems difficult, as all of them are nearly alike. Thus no specific name has been proposed.

Genus RHINOPTERA (ZYGOBATES)
Muller, 1834
RHINOPTERA RAEBURNI White, 1934
Pl. 88, fig. 11

Material.—Two isolated tooth fragments.

Description.—The teeth are of hexagonal shape. The anterior and posterior faces slant. The crown slopes forward. The crown is extremely thick and the anterior and posterior surfaces have fine vermiculating ridges. The coronal surface has a lumpy appearance. The root is rather coarsely ridged and grooved.

Measurements.—Length, 6 mm.; height, 7 mm. The breadth could not be determined.

Genus RHINOPTERA SHERBORNI White, 1926
Pl. 88, fig. 14

Material.—One isolated tooth fragment.

Description.—This specimen is hexagonal in shape and is similar in appearance to *R. raeburni.* The anterior and posterior faces slant forward. The coronal surface is thick

and the anterior and posterior surfaces have fine vermiculating ridges. The coronal surface has a lumpy appearance. The root is thin in comparison to the crown. The tooth is comparatively small.

Measurements.—Length, 3 mm.; height, 3.5 mm.

Discussion.—In spite of the general similarity of the specimen with *R. raeburni*, its smallness and thinness of root establish its identity.

Genus AETOBATIES Muller & Henle, 1841

AETOBATIES ARCUATUS BARIPADENSIS Ghosh, n. var.

Pl. 88, figs. 12,17,18

Material.—One isolated tooth.

Description.—The tooth is hexagonal and arched laterally. The two sides of the crown meet at a broad obtuse angle. The lower surface is symmetrically arched. The triturating surface is worn off in a convex manner anteriorly. The ridges and grooves continue from the under side to the posterior borders of the enamelled surface. A short distance from the border of the root, the ridges bifurcate and continue to the end (Pl. 88, fig. 17). The under side and the posterior face of the tooth meet at an acute angle, whereas anteriorly they form a right angle.

Measurements.—Length, 9 mm.; breadth, 29 mm.; height, 5 mm.

Discussion.—The specimen is similar to *A. profundus* Cope, figured and described by Leidy (1877), but Leriche (1942) has put it in synonymy with *A. arcuatus*.

The present specimen differs from *A. arcuatus* in that the root bifurcates on the underside. For this reason the specimen is referred to a new variety. The varietal name is given after the town of Baripada.

Family TRYGONIDAE

Genus HYPOLOPHUS Muller & Henle, 1841

HYPOLOPHUS SYLVESTRIS MOHULIYI Ghosh, n. var.

Pl. 88, figs. 2,9; Text-fig. 1

Material.—One isolated tooth.

Description.—The tooth is hexagonal in shape and its terminations are pointed (Text-fig. 1). The breadth is slightly more than the length. The coronal surface is convex both antero-posteriorly and laterally. Both the anterior and posterior borders slope backward. Thus the anterior margin overhangs the root. The root is as high as the crown, but the area covered by the root is less than that of the crown. The root is divided by a single deep medial furrow.

TEXT-FIG. 1—Diagram showing the slope of the anterior and posterior borders of *Hypolophus sylvestris mohuliyi* Ghosh, n. var.

Measurements.—Length, 3.5 mm.; breadth, 7.5 mm.; height, 3 mm.

Discussion.—The present species is allied to the species described by White (1931) from the Eocene of England. The only point of difference is that whereas in the former the sides of the crown always slope inwards, in the latter only the anterior side slopes in the same manner, and the posterior runs parallel to it. Due to this difference in crown characteristics, the author refers his specimen to a separate variety. The varietal name is taken from a nearby village.

CONCLUSIONS

One interesting feature of the above findings is the presence of species restricted to Eocene in the assemblage. The fossils identified with their ranges in time are shown in the table below.

On the basis of the fossil teeth it is evident that age of the bed that yielded them is Eocene. But Eames reported the presence of *Ostrea gajensis*, a characteristic species of the Gaj horizon (Miocene), from the same bed.

TABLE 1—STRATIGRAPHIC RANGES OF SPECIES AND VARIETIES

Species or Variety	Range
Carcharodon megalodon	Eocene-Pliocene
C. megalodon var. *robustus*	Eocene-Pliocene
Carcharhinus frequens	Eocene-Oligocene
C. egertoni	Eocene-Miocene
Hemipristes serra	Eocene-Pliocene
Pristes aquitanicus	Eocene?, Oligocene?, Miocene
Rhinoptera raeburni	Eocene
R. sherborni	Eocene
Myliobatis sp.	questionable
Hypolophus sylvestris	Eocene

So there are two alternatives. Firstly, it may be that the age of the bed is Eocene and that *Ostrea gajensis* is not restricted to the Miocene. Secondly, the above three Eocene fossils, *Rhinoptera raeburni*, *R. sherborni*, and *Hypolophus sylvestris* may have a wider range and not be restricted to the Eocene alone. No definite conclusion can, however, be reached at the present state of knowledge. Further work, which is in progress, may fix conclusively the age of the bed.

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 680–681, PL. 89, JULY 1959

AN OCCURRENCE OF *DESMOGRAPTUS CANCELLATUS* IN THE STEWARTVILLE DOLOMITE OF MINNESOTA

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IN JULY 1958, while a student in a field course in geology conducted by the author, Mr. Duane Hyland found a single specimen of the dendroid graptolite *Desmograptus cancellatus* (Hopkinson) in the middle Ordovician Stewartville member of the Galena formation. On checking in Ruedemann (1947), Stauffer & Thiel (1941) and Weiss (1957), the author found no record of this species from the upper Mississippi Valley. A short note describing the occurrence seemed advisable.

The specimen was found 11 feet above the floor of the lower of two quarries exposing the Stewartville at the Rifle Hill locality (Sloan & Weiss 1956, p. 99; Weiss 1957, p. 1053) and 42.5 feet below the contact with the overlying Dubuque formation. The Rifle Hill locality is in the NW¼ Sec. 35 T102N, R12W, Fillmore County, Minnesota. The stratigraphic section was remeasured by tape since new exposures exist as a result of quarrying. The entire thickness of the Prosser member of the Galena formation is now exposed and totals 56.7 feet. The entire thickness of Stewartville is exposed and totals 63.1 feet. The contact between the Prosser and Stewartville members was placed about 14 feet higher in the section than in Sloan & Weiss 1956, p. 99. However the two members are gradational and the exact location of the contact is somewhat subjective.

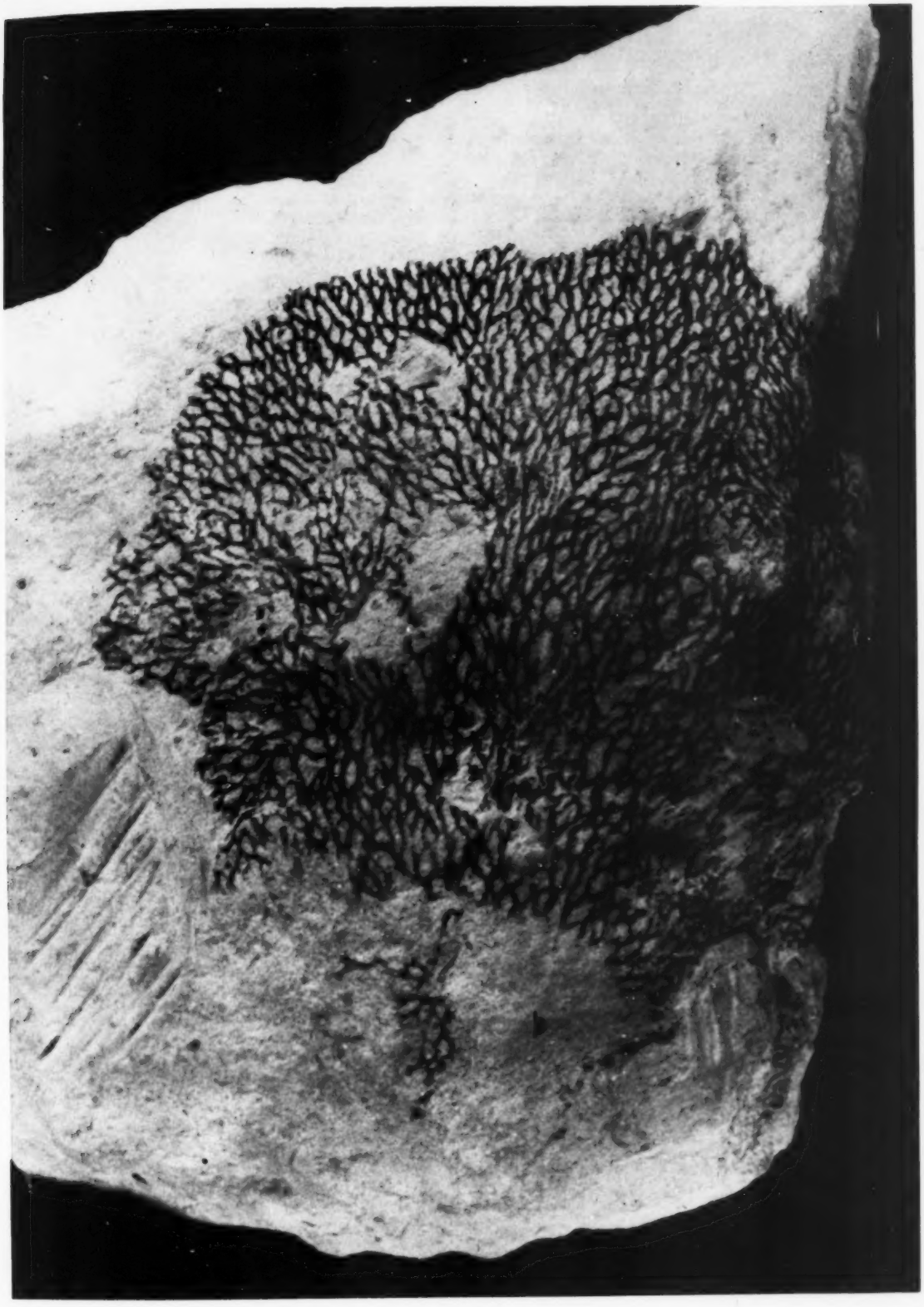
The specimen was found 6 feet above the base of the upper *Receptaculites oweni* zone, associated with *R. oweni* Hall, *Catenipora gracilis* Sinclair & Bolton, *Streptelasma corniculum* Hall, *Westonoceras minnesotense* (Clarke) and *Hormotoma* sp. The lithology is a mottled recrystallized, calcareous dolomite.

The inverted, conical rhabdosome was preserved in orientation in the matrix. The apex of the cone had broken off in blasting and was lost. The estimated length of the cone is 65 mm. The cone was deformed during compaction of the surrounding sediment, with one side bent in over the open end of the cone. The opening of the cone at present is elliptical and measures 30 mm. wide and 54 mm. long. The thecae appear to be bundled as in *Koremagraptus* with many thecae making up a single strand. The average width of the strands was .23 mm., the extreme values measured were .15 mm. and .40 mm. The strands form an anastomosing network with fairly even sized meshes between strands. The extreme values of length of the meshes are 4.0 mm. and .7 mm.; the average length is 1.84 mm. The extreme values of the width of the meshes are .3 mm. and 1.0 mm.; the average width is .61 mm. Dissepiments are absent.

Sproule (1936, p. 102) found *D. cancellatus* only in the upper 20 feet of the Cobourg limestone at Craigleith, Ontario. Caley (1936, p. 31) found this species in the Collingwood of Little Current on Manitoulin Island, Ontario. These are the nearest occurrences of this species both geographically and stratigraphically. The specimen is on deposit in the Geological Museum of the Department of Geology, University of Minnesota, under the catalog number 8285.

EXPLANATION OF PLATE 89

Latero-basal view of representative of *Desmograptus cancellatus* (Hopkinson) from the middle Ordovician Stewartville Dolomite, Fillmore County Minnesota, ×2½. The letter b indicates the base of the rhabdosome.



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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 682–684, JULY 1959

CHANGES IN THE CHEMICAL COMPOSITION OF PTEROPOD SHELLS AFTER DEPOSITION ON THE SEA FLOOR

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ABSTRACT—Aluminum, magnesium, manganese, copper and strontium concentrations in modern and fossil pteropod shells are examined. Post-depositional mixing on the sea floor is indicated by the presence of stained and unstained pteropod shells in the same layer of core material.

INTRODUCTION

THE question of trace element change in shell material with time has been discussed by Vinogradov (1953) and Lowenstam (1954, 1959) who suggest that biochemical evolution has occurred. On the other hand Krinsley (1956) has shown that in some littoral gastropods differences in the trace element composition of modern and fossil specimens of the same species are due to post-depositional changes rather than biochemical evolution. The present work is an extension of these studies to planktonic gastropods. It supplements knowledge of the chemical composition of pteropod shells as reported by Vinogradov (1953) and Nicholls, Curl & Bowen (1958).

MATERIALS AND METHODS

Pteropods were removed from oblique plankton samples taken in the Atlantic Ocean, the Mediterranean and Caribbean Seas, and the top three centimeters of two Mediterranean cores. The locations of the plankton samples and cores are given in Table 1.

Where necessary, the associated organic matter was removed by dissection. After careful examination to make sure it was free of extraneous material, each specimen was washed in distilled water, and crushed and analyzed spectrographically in duplicate. The techniques reported in Bieri & Krinsley (1959) were followed except that the shells were not ashed.

Seven analyses were made on *Styliola subula* Quoy & Gaimard which was the most abundant pteropod in the surface plankton and core samples. Four analyses were made on *Euclio pyramidata* (Linné) which was next most abundant. One analysis each was made on *Euclio cuspidata* (Bosc), *Creseis acicula* Rang and *Cavolinia gibossa* (Rang). These specimens are warm water pteropods and in general occur in the upper 300 to 400 meters of the ocean. The pteropods are oceanic species rarely found close to shore

TABLE 1—SAMPLE COLLECTING LOCALITIES

Plankton Sample #	Locality	Depth in Meters All Tows Oblique
P-1	19°14′N; 76°51′W (Caribbean Sea)	0–670
P-2	18°42′N; 79°43′W 19°11′N; 77°56′W (Caribbean Sea)	0–380 0–400
P-3	17°46′N; 70°05′W (Caribbean Sea)	0–325
P-4	38°37′N; 63°10′W 40°52′N; 51°07′W (Atlantic Ocean)	0–345 0–230
P-5	Several miles off the eastern coast of Bermuda. (Atlantic Ocean)	0–400
P-6,7,8,10	15 samples scattered over large portions of Mediterranean SeaR combined.	0–±400
P-9	41°55′N; 55°25′W (Atlantic Ocean)	0–240
Core #		
C-1	34°23′N; 24°06′E (Mediterranean Sea)	—
C-2	34°37′N; 23°25′E (Mediterranean Sea)	—

TABLE 2—PTEROPOD SHELL ANALYSES—% BY WEIGHT

Sample #	Al	Cu	Mg	Sr	Mn
		Styliola subula			
P-1	.0007	.0013	.022	.10	.0015
P-2	.0006	.0015	.019	.11	.0014
P-3	<.0003	<.0008	.011	.10	.0014
P-4	.0008	.0020	.036	.10	.0003
P-5	.0008	.0015	.011	.10	.0003
P-6	.0007	.0019	.025	.095	.0002
C-1	.0025	.010	.056	.14	.0005
		Euclio pyramidata			
P-7	.0006	.0014	.016	.085	.0003
C-2	—	.0008	.090	.095	.059
C-1 Brown Shells	.040	.0014	.096	.11	.0074
C-1 White Shells	.23	.0011	.060	.11	.0013
		Cavolinia gibossa			
P-8	.0007	.0019	.017	.10	.0002
		Creseis acicula			
P-9	—	—	.015	.11	.0003
		Euclio cuspidata			
P-10	.0003	.0008	.012	.095	.0005

except *Creseis acicula* which is sometimes very abundant in near shore waters.

RESULTS

Five elements—aluminum, copper, magnesium, strontium and manganese—were determined quantitatively (Table 2).

Aluminum.—Aluminum appears to be fairly constant in modern material, varying from <.0003% to .0008%. It is considerably more abundant in core material, varying from .0025% to .23%. The high variability of the core material may indicate that the increase in aluminum is due to contact with the surrounding sediments. There are no significant differences in aluminum concentrations between geographic areas, genera or species in the modern material.

Copper.—Copper is fairly constant in modern material, varying from <.0008% to .0020%. In Core 1, *Styliola subula* has a copper content larger by a factor of five than does *Euclio pyramidata*, which has gained little or no copper. There are no significant differences in copper concentrations between geographic areas, genera or species.

Magnesium.—Magnesium concentrations in modern pteropods vary from .011% to .036% with no significant differences between geographic areas, genera or species. That magnesium from the sediments accumulates in both *Styliola subula* and *Euclio pyramidata* is indicated by the relatively high value in the cores (.056% to .096%). Krinsley (1956) has found that magnesium can move in or out of littoral gastropod shells during the process of fossilization, without recrystallization of the shell material.

Strontium.—Strontium varies over a relatively small range of .095% to .14% in modern and fossil material. Emiliani (1955) reported a small variation of strontium in pelagic foraminifera from core material. Krinsley (1956) has found a similar small variation in 148 specimens of three species of littoral gastropods.

Manganese.—Manganese concentrations in modern *Styliola subula* are higher in Caribbean than in Atlantic or Mediterranean samples. *Euclio pyramidata, Euclio cuspidata, Cavolinia gibossa* from the Mediterranean and *Creseis acicula* from the Atlantic have concentrations of manganese similar to *Styliola subula* from the Mediterranean and Atlantic, all considerably lower than modern *Styliola subula* from the Caribbean. This may indicate that geographic lo-

cation is more important in the concentration of manganese than is the genus or species.

Emiliani (1955) found higher manganese, aluminum, silicon, iron and magnesium concentrations in foraminiferal tests from cores in the Caribbean than from the Equatorial Atlantic or Pacific Oceans. He suggested that this is due either to different degrees of sample washing or to the greater abundance of these elements in the Caribbean. The ability of modern *Styliola subula* to concentrate manganese may depend upon the amount available. If this is the case and if diagenetic effects in core specimens are not present or can be corrected for, such shells might indicate the amount of manganese present in a particular ocean of the past.

The highest manganese concentration was found in *Euclio pyramidata* from Core 2.

Core 1 contained specimens of *Euclio pyramidata* which were extremely white and clean and could not be distinguished by eye from plankton net samples. Other specimens of *E. pyramidata* in the same layer were a light to dark brown color. Manganese was more concentrated in the brown shells than in the white.

The mixture of the brown and white shells (gradations between white specimens and brown ones did not occur) suggests a mixing of bottom sediments either during the time the core was taken or previously. Careful examination of the core revealed that the pteropod layer was quite distinct, indicating that the mixing occurred before the core was taken. If the dark shells had remained on the surface of the sediments for some time to permit precipitation of the brown material and then had been buried, subsequent mixing of these shells with white specimens that had not been exposed to surface conditions for any length of time would have produced the condition observed. This phenomenon might be used as a criterion for reworking of core sediments.

SUMMARY

Aluminum, manganese and magnesium concentrations are generally higher in pteropod shells from cores than in shells from plankton samples. These higher concentrations are probably the result of uptake from sediments on the ocean floor. Core and plankton samples seem to contain about the same concentrations of copper and strontium, except for one copper core analysis. Both of these elements might be good standards to use in the study of post-depositional change. No elements were found which will distinguish one species from another. Shells of *Styliola subula* from Caribbean plankton were exceptional in having markedly higher manganese concentrations than shells from the Atlantic, the Mediterranean, and a core sample.

Post-depositional mixing on the sea floor may be indicated by the presence of stained and unstained pteropod shells of the same species in the same layer of core material.

ACKNOWLEDGEMENTS

The specimens on which this paper is based were prepared in the biology section and analyzed in the geochemistry section of Lamont Geological Observatory of Columbia University. The work was partially supported by a grant from the Rockefeller Foundation. Part of the material was collected from the research ship Vema in connection with coring and seismic studies. The remaining material was collected by William Beebe off the coast of Bermuda between 1930 and 1931. A. Hargrove and R. Menzies helped with specimen preparation.

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 685–699, 7 TEXT-FIGS., JULY 1959

PALEONTOLOGICAL NOTES

PLEISTOCENE MOLLUSCAN NOTES. I. THE BAY POINT FORMATION AT ITS TYPE LOCALITY

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INTRODUCTION

Mission Bay is a shallow depression that lies between Soledad Mountain and Point Loma, San Diego County, California. To the southeast it is separated from San Diego Bay by the delta of the San Diego River. A broad, flat-topped peninsula, formerly called Bay Point but named Crown Point on the La Jolla 7½-minute quadrangle, extends into the bay from the south flank of Soledad Mountain. Light gray, cross-bedded coarse sands and gravel, the type exposures of the Bay Point formation, crop out along the west side of the point (Text-fig. 1). These sediments are highly fossiliferous, containing especially an abundance of *Donax gouldi*, and are chiefly well-cemented. Much of the exposed material is a *Donax* coquina.

Stephens (1929, p. 253) first directed attention to the deposits at Crown Point. He listed a fauna of six pelecypods and an echinoid from these exposures: *Chione succincta* [*Chione californiensis*], *Paphia staminea* [*Protothaca staminea*], *Tivela stultorum*, *Amiantis callosa*, *Macoma secta*, *Donax laevigata* [*Donax gouldi*], and *Dendraster excentricus*. Grant & Hertlein report that the Panamanian echinoid *Mellita longifissa* was collected from this deposit by Junius Henderson (1938, p. 101–102). In 1939, Hertlein & Grant named the Bay Point formation, with the exposures at Crown Point as the type locality. Excellent photographs of the type exposures have been published by Hertlein & Grant (1939, fig. 8; 1944, pl. 14).

The writer is indebted to Takeo Susuki, University of California, Los Angeles, and E. P. Chace, San Diego Society of Natural History, for access to collections under their care, and to Mrs. Mathilda Van Zell, Standard Oil Company, California, for aid in collecting.

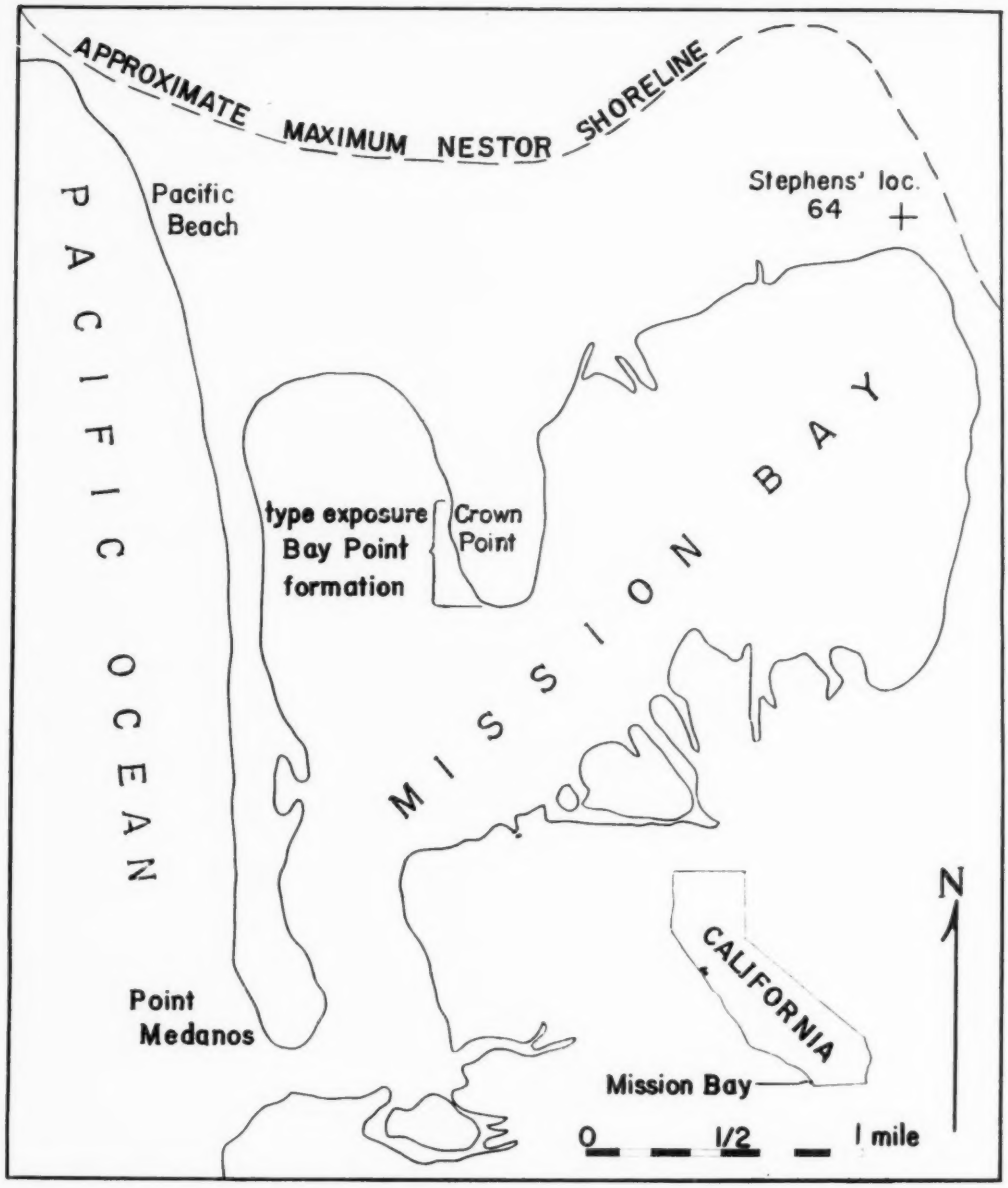
STRATIGRAPHIC POSITION

The base of the Bay Point formation is not exposed at Crown Point, but it evidently rests upon the marine platform surface, cut into the Pliocene (?) San Diego formation, that is exposed in sea cliffs at Pacific Beach. The shore-line angle of this terrace is not exposed, but probably is at an elevation of between 60 and 70 feet, and thus represents the Nestor terrace of Ellis (*in* Ellis & Lee, 1919). The possibility that a terrace younger than the platform at Pacific Beach is eroded into "Nestor" sediments at Crown Point, and that the Bay Point formation rests upon such a younger surface, probably does not merit consideration. It is however possible that Pleistocene sediments older than the time of formation of the Nestor terrace underlie the Nestor surface to the south in Mission Bay. This is true at least in San Diego Bay, for Upper Pleistocene fossils from sands exposed in excavations for Naval installations at levels well below the Nestor platform surface along the San Diego waterfront are in the collections of the San Diego Society of Natural History.

The flat upper surface of Crown Point doubtless corresponds to the surface developed just above 25 feet in altitude at North Island, Coronado Island, and in the Coronado Heights—South San Diego district. Probably this is not a surface of marine planation, although it has been mapped in part as the Tia Juana terrace by Ellis (*loc. cit.*).

FAUNAL COMPOSITION

The molluscan fauna is summarized in Table 1. This list is based chiefly on collections made by the writer (U.C.L.A. localities 3603A–D) and on the previous literature reviewed above; however, it also includes species in the collections of the San Diego Society of Natural History and the University of California, Los Angeles, labelled as from the Pleistocene of Bay Point. As each of these collections contain specimens that, to judge from their condition, probably represent the Recent fauna of



TEXT-FIG. *1*—Index map showing the location of the type exposure of the Bay Point formation, and the approximate position of the shore line at maximum sea-stand on the Nestor terrace. Base map, La Jolla Quadrangle, U. S. Geol. Survey, 7½-minute series.

Mission Bay (Two of the species are *Plagioctenium circularis* and *Chione fluctifraga*), other species known only from these collections are suspect, and are marked with an asterisk in Table 1. There remain 30 identified mollusks known definitely to occur in the Pleistocene at Crown Point. The only species of echinoid found in the collections studied is identified as *Dendraster excentricus* Eschscholtz.

TABLE 1—MOLLUSKS FROM THE PLEISTOCENE OF CROWN POINT, SAN DIEGO COUNTY, CALIFORNIA

PELECYPODA

Nucula exigua Sowerby
Leptopecten latiauratus (Conrad)
Serridens oblonga Carpenter
Chione californiensis (Broderip)
Protothaca staminea (Conrad)
**Protothaca tennerima* (Carpenter)
Tivela stultorum (Mawe)
Amiantis callosa (Conrad)
Saxidomus nuttalli Conrad
Macoma secta (Conrad)
**Semele decisa* (Conrad)
Donax gouldi Dall
Schizothaerus nuttali (Conrad)

SCAPHOPODA

Dentalium neohexagonum Sharp & Pilsbry

GASTROPODA

Fissurella volcano Reeve
Tegula ligulata (Menke)
Liotia acuticostata (Carpenter)
Halistylus pupoideus (Carpenter)
Pomaulax undosus (Wood)
Littorina scutulata Gould
Epitonium sp.
Pseudorotella invallata (Carpenter)
Pseudorotella supravallata (Carpenter)
Alvania acutelirata Carpenter
Barleeia haliotiphila Carpenter
Rissoina nereina Bartsch
Caecum californicum Dall
Seila montereyensis Bartsch
Hipponix tumens Carpenter
**Crepidula onyx* Sowerby
**Crucibulum spinosum* (Sowerby)
Neverita reclusiana alta Arnold
**Neverita reclusiana imperforata* (Dall)
"Nassa" fossata (Gould)
Olivella biplicata (Sowerby)
Coleophysis harpa (Dall)
Turbonilla torquata Gould
Turbonilla sp.

Representatives of all these species live today in the eastern Pacific, although one, *Rissoina nereina*, is known to live only well to the south, from Punta Abreojos to Cabo San Lucas, Baja California. *R. nereina* is not previously recorded from the Californian Pleistocene, but is known as a fossil in the Panamanian province (Jordan, 1936, p. 114). Another species, *Serridens oblonga*, has not been recorded heretofore as a fossil.

Donax gouldi is so abundant at Crown Point that all other species are quite rare by comparison. If *Donax* is disregarded and relative abundances estimated among the remainder of the molluscan fauna, *Tivela stultorum* is common, and *Amiantis callosa* is common in some lenses but is rare in the fauna as a whole. Other species are represented in the collections by only one or two individuals. Because the sands are well-cemented, collecting is difficult; most of the smaller species were recovered from soft, only slightly cemented pockets. The echinoid *Dendraster excentricus* is common.

SIGNIFICANCE

Because of the preponderance of the exposed sandy beach clam *Donax*, Hertlein & Grant have suggested that the Bay Point formation is an "open sandy beach" deposit at Crown Point (1944, p. 67). All evidence at hand strongly supports this interpretation. Crown Point is interpreted as an ancient bar, analogous to the Recent bar extending across the mouth of Mission Bay to Point Medanos (Text-fig. 1). That shallow-water sea temperatures near the bar were warmer than today is suggested by the presence of *Rissoina nereina* and of *Mellita*. This bar doubtless protected the Pleistocene Mission Bay to the east from strong wave action; a quiet-water Pleistocene fauna has been recorded from the northeast corner of Mission Bay by Stephens (1929, loc. 64). A warm water temperature behind the bar is indicated by a southern species, *Chione gnidia* (Stephens, 1929). No northern species that might be regarded as frigophilic are present in collections from Bay Point. As the Crown Point bar was surely well above wave base, supporting as it did an exposed sandy shore community, it must have been built when the sea stood considerably below its greatest extent on the Nestor platform.

Although the Bay Point formation has a limited outcrop area, being exposed in patches at Torrey Pines Park, Pacific Beach, western Point Loma, along the margins of San Diego Bay, and in sea cliffs to the south near the International Boundary (Emerson & Addicott, 1954) and in northwestern Baja California (Valentine, 1957), its recognition as a formal stratigraphic unit seems justified. It has yielded large and varied faunas of diverse biofacies at these

localities, and forms an important record of Late Pleistocene history in this region.

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TURRITELLA GRANTI, A NEW PLEISTOCENE GASTROPOD FROM PALOS VERDES HILLS, CALIFORNIA

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A large collection of fossils was made in 1949 by Mr. Carl Helms from an exposure of Lower Pleistocene strata on the northern margin of Palos Verdes Hills, California (Text-fig. 1). Mr. Helms, now of the Standard Oil Company of California, was at that time working under the direction of Prof. W. P. Popenoe, University of California, Los Angeles. Among the fossils is a single specimen of a new *Turritella*. This shell is so distinctive that its formal description is justified.

The strata collected by Helms have been assigned to the Timms Point silt by Woodring et al. (1946, pl. 1, loc. 66) on the basis of the occurrence of *Pandora grandis*, *Mya truncata*, and a small form of *Panomya beringianus*, all cold water pelecypods that characterize Timms Point silt assemblages. Two species of *Turritella* are previously known from Lower Pleistocene deposits of California, *cooperi* and *pedroensis*. Both are abundant in the Helms collection. Efforts to obtain additional specimens of the new *Turritella* by re-collecting were unsuccessful.

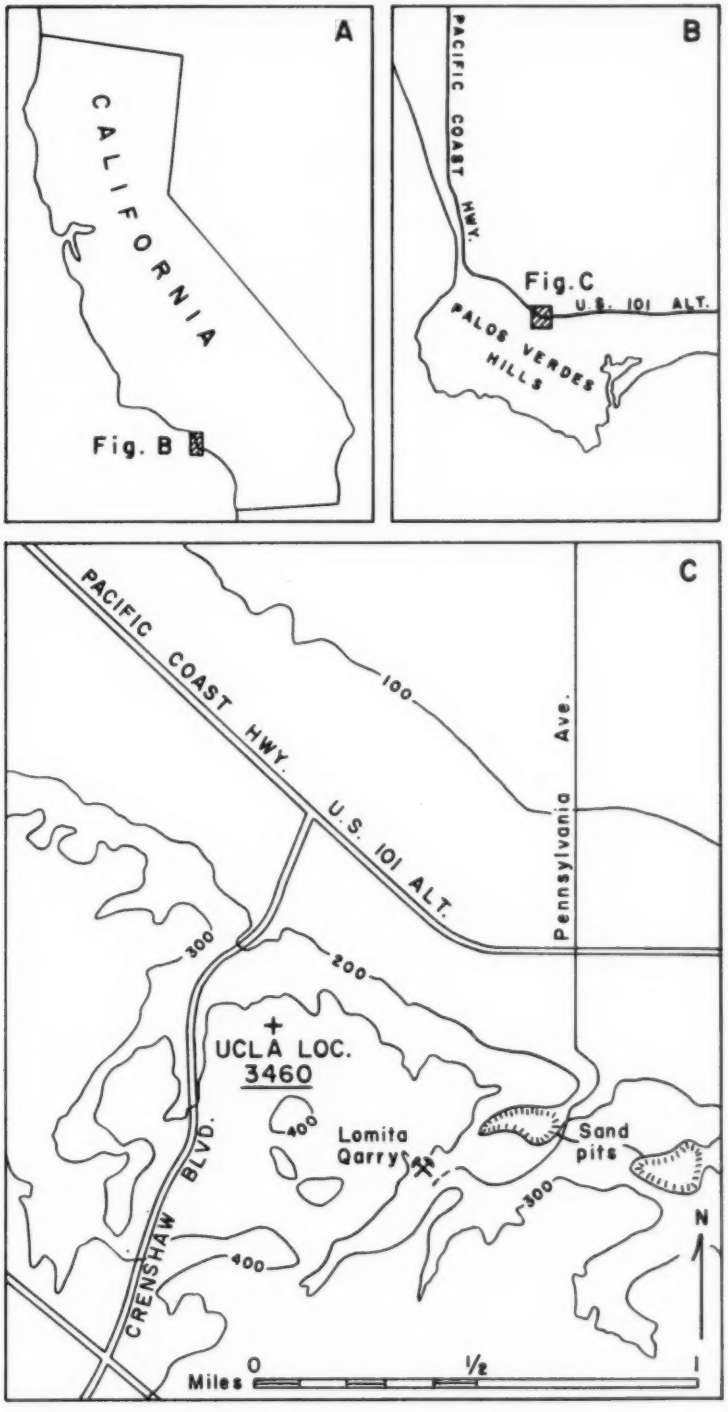
Genus TURRITELLA Lamarck, 1799

Turritella LAMARCK, 1779, Mem. Soc. Hist. Nat. Paris, ser. 1, v. 1, p. 74; GUILLAUME, 1924, Bull. Soc. Geol. France, ser. 4, v. 24, p. 281–311, pls. 10–11; MERRIAM, 1941, Univ. Calif. Pubs. Dept. Geol. Sci. Bull., v. 26, no. 1, 214 p., 41 pls; MARWICK, 1957, Malac. Soc. London Proc., no. 32, pt. 4, p. 144–166.

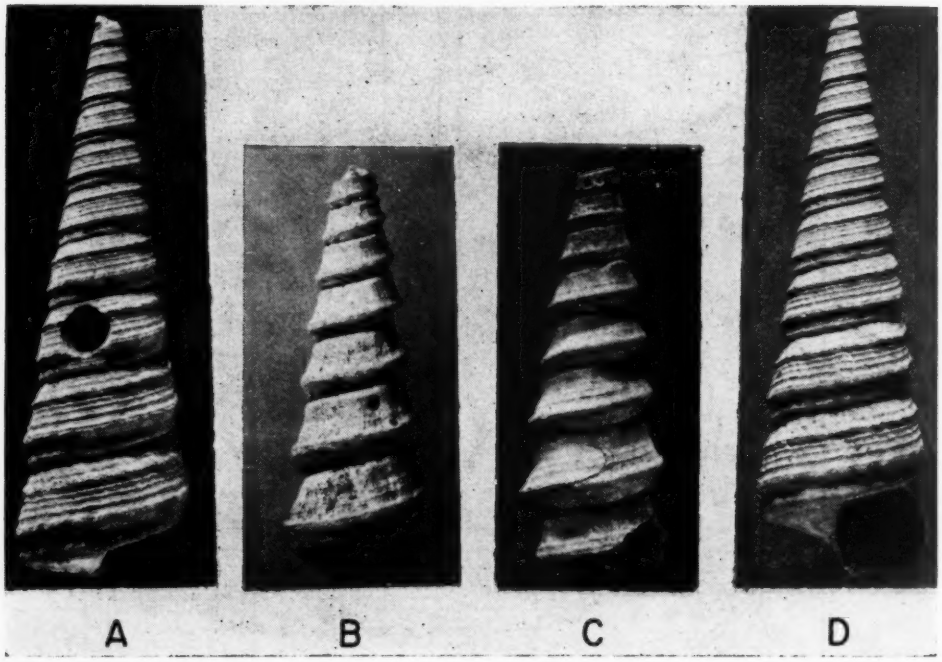
TURRITELLA GRANTI Valentine & Susuki, n. sp.
Text-figs. 2B–C, 3A

The shell is rather small for the genus and the pleural angle is narrow, 17°, on the type. The apical whorls are missing. Adult whorls are carinate below the center; the whorl profile is concave above and gently convex to straight below the carina. In addition to a spiral cord at the carina, the whorls are ornamented by two faint spiral threads, placed above the carina and just posterior to the center of the whorls. Both spiral threads are absent on early whorls and strengthen towards the aperture; the anterior thread is strongest and is developed earliest. A few faint spiral lines also ornament the whorl sides and the base. The sutures are deeply impressed. The apertural margin is broken and the aperture appears nearly rounded.

The growth line angle is slightly negative, about 6°–8° on the early whorls and 2°–4° on later whorls, as the antispiral sinus is shallow, and the growth line at the maxi-



TEXT-FIG. 1—*A*, map showing location of outcrop from which holotype of *Turritella granti* was collected. *B*, index map showing relation of area in A (ruled) to Palos Verdes Hills, California. *C*, enlargement of ruled area in B.



TEXT-FIG. 2—*A, D, Turritella cooperi* Carpenter, Hypotype no. 28724, U.C.L.A. Intertebrate Paleontology collections. From same locality as *T. granti*. ×2. *B, C, Turritella granti* Valentine & Susuki, new species, Holotype no. 28013, U.C.L.A. Invertebrate Paleontology collections. U.C.L.A. locality 3460. ×2.

mum of the spiral sinus is in a more apertural position than the posterior end of the growth line. The maximum of the spiral sinus is at the carina; the maximum of the antispiral sinus is slightly variable, about at the posterior spiral thread.

Holotype.—No. 28013, Invertebrate Paleontology Collections, University of California, Los Angeles.

Dimensions.—(Incomplete holotype) length, 26.3 mm.; width of last complete whorl, 10.6 mm.; height of last complete whorl, 5. 5. mm.

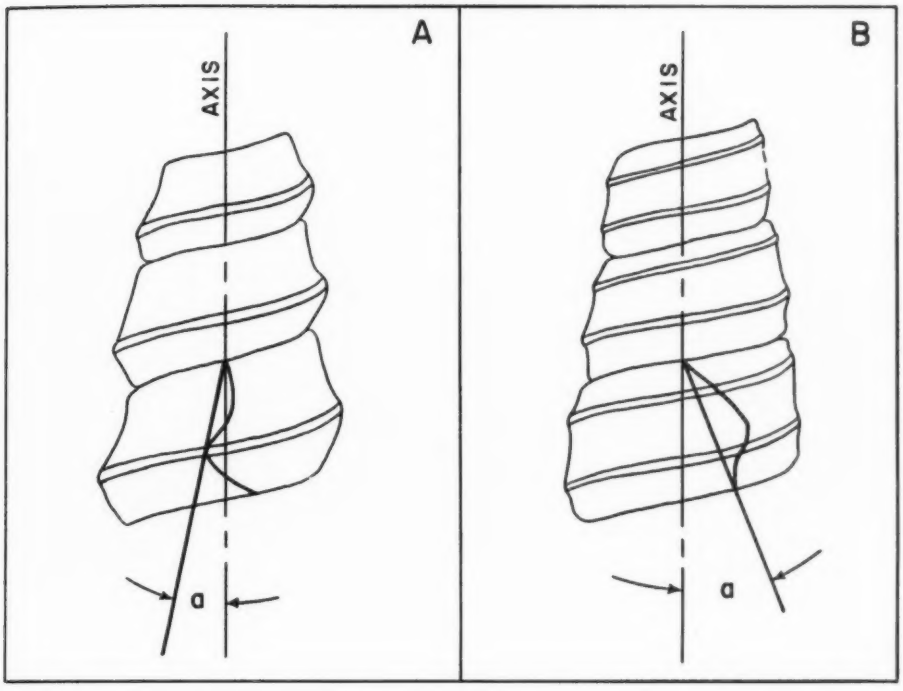
Occurrence.—U.C.L.A. locality no. 3460. Silty sandstone exposed 1,000 feet east of Crenshaw Boulevard and 2,250 feet slightly west of south of the intersection of Crenshaw and U. S. Highway 101, at about 345 feet elevation, in the second ravine east of Crenshaw cutting the north slope of 400 foot hill, northern border of Palos Verdes Hills, Los Angeles County, California. Lower Pleistocene. Carl Helms, Collector.

Known only from the type locality.

Remarks.—The whorl profile and form of the growth line serve to separate this species from all previously described west North American species of *Turritella*. The development of the spiral sinus is particularly diagnostic, for in no other known west North American species does its maximum lie so high on the whorl or so far towards the aperture. As a result, the growth line angle is measured to the left of the shell axis, and may be described as negative (Text-fig. 3A).

As the holotype is broken anteriorly, it is possible that this species is larger when mature than the type dimensions indicate.

It was suggested by paleontologists with whom we conferred that *granti* might be an aberrant form of *cooperi* (Text-fig. 2A,2D), and we have entertained this possibility. However it does not seem that the *granti* growth line form can be developed from *cooperi* by warping. The *cooperi* growth line,



TEXT-FIG. 3—*A*, growth line form and angle of *Turritella granti*, showing unusual "negative" growth line angle (a) and high maximum of spiral sinus, at carina. *B*, growth line form and angle of *Turritella cooperi*, showing positive growth angle (a) and low maximum of antispiral sinus, at anterior spiral.

itself very characteristic as Merriam has emphasized (*op. cit.*, p. 118), displays a remarkably anterior maximum of the antispiral sinus, while the maximum of the spiral sinus is at or near the anterior margin of the whorl, commonly on the base (Text-fig. 3B). Even if the carina of *granti* be assumed to represent the basal spiral of an aberrant *cooperi*, the remaining growth line trace does not agree.

If the apertural profile in *Turritella* as reflected in growth lines is indeed a conservative character of supra-specific importance as the work of Guillaume, Merriam, and Marwick has indicated, then *granti* may belong to a stock that is not otherwise recorded from the Pacific Coast.

This species is named for U. S. Grant, IV, Professor of Geology, University of California, Los Angeles.

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ABUNDANCE AND STRATIGRAPHIC DISTRIBUTION OF DEVONIAN AND MISSISSIPPIAN CONODONTS IN THE UPPER MISSISSIPPI VALLEY

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Illinois Geol. Survey, Urbana, Univ. Houston, Houston, Texas, and Univ. Texas, Austin

During the past several years the authors have conducted for the Illinois State Geological Survey a continuing study of the stratigraphic usefulness of conodonts in Devonian and Mississippian rocks of the upper Mississippi Valley. These studies are based on a series of nearly continuous consecutive samples taken from the longest and most nearly complete exposures available, consistent with careful geographic spacing. As a matter of routine each sample is weighed and the number of conodonts found in each is recorded. Thus, even though we are mainly interested in stratigraphic ranges of genera and species, a considerable amount of numerical data on the distribution of conodonts has accumulated. These data show the fossils to be far more widely distributed than formerly believed and seem to indicate an inverse relation between rate of sedimentation and abundance of conodonts.

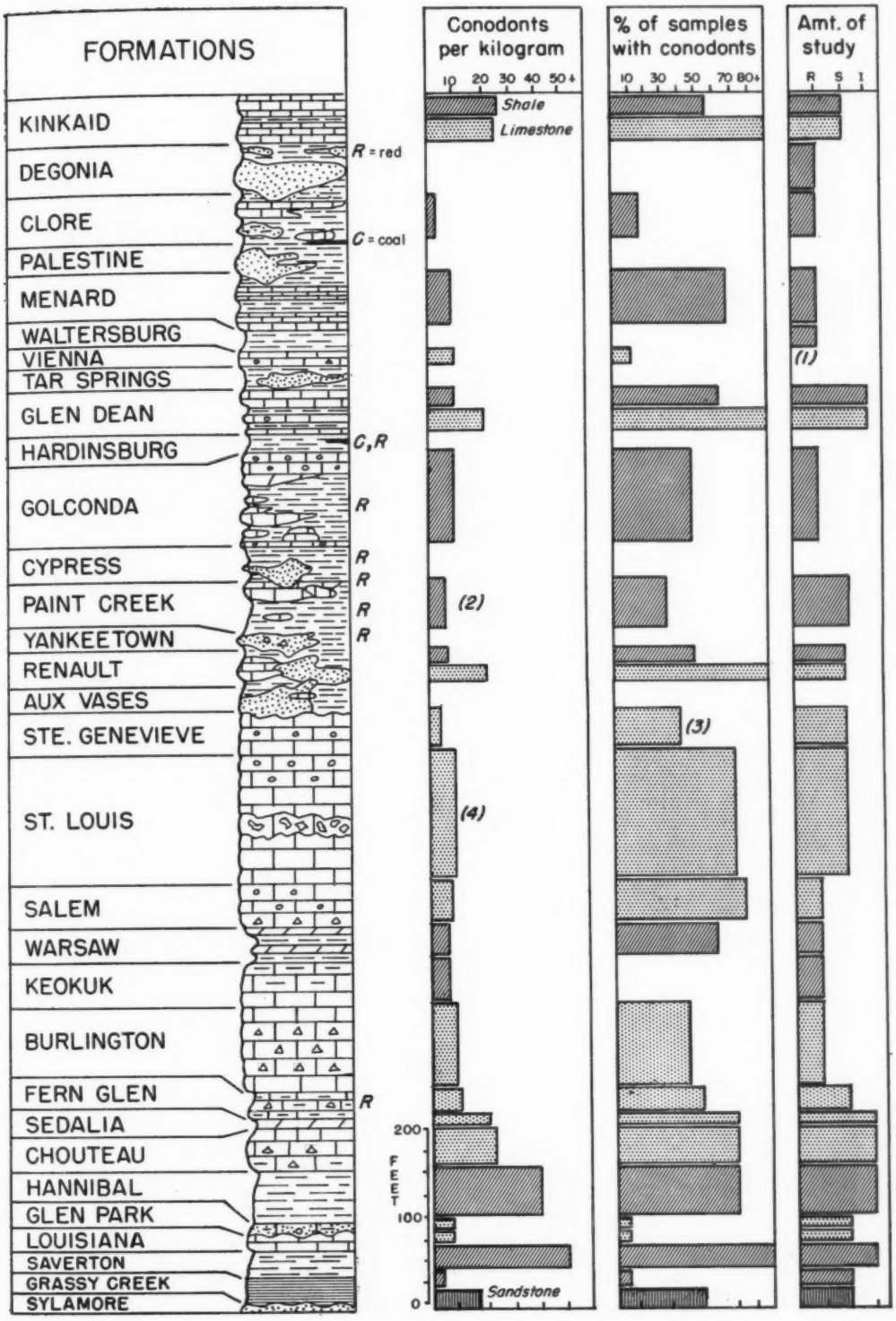
Two main methods are used to free conodonts from the samples. The dried shales are soaked in Stoddard's solvent (dry cleaners' solvent) for three to seven days. Next the solvent is decanted and replaced by water. By soaking in water for one or two days most shales are reduced to a sludge. The sludge is washed through a series of screens and the portion retained between the 20- and 100-mesh screens is concentrated by gravity separation in tetrabromoethane. Shales that are not reduced to sludge by the Stoddard's solvent are boiled prior to screening.

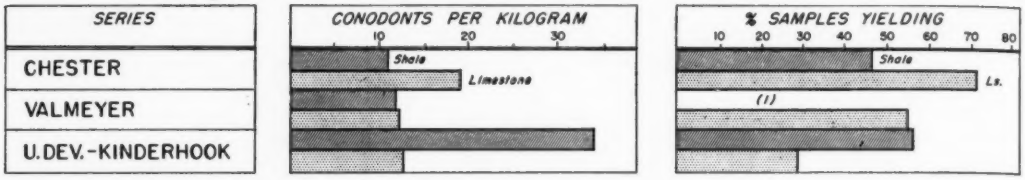
Limestone and calcareous sandstone samples are crushed to less than $\frac{5}{8}$ inch size and placed in 10 percent acetic acid. The residues are then wet sieved and concentrated in the same manner as shales.

The stratigraphic section and information taken from the samples are summarized by Text-figure 1. Text-figure 2 shows the relative abundance of conodonts by series and lithology. Gaps in the graphs of Text-figure 1 represent stratigraphic zones in which there is relatively little reliable information; a result of the fact that our studies are less than half completed. Notable in the gaps are the sandstones, most of which have been sampled only casually because they are in general nonfossiliferous. In the initial stages of the study only one lithology, either limestone, shale, or sandstone, was sampled from any given formation that in-

TEXT-FIG. *1*—Generalized geologic column showing formations that were examined for conodonts. The left-hand graph shows the average number of identifiable specimens found per kilogram of sample. The middle graph shows the percentage of samples that yielded identifiable conodonts. The right-hand graph indicates the amount of study given to each formation. R (for *reconnaissance*) indicates study of one or two outcrop sections from which nearly continuous channel samples were examined; S (for *standard*) indicates two to four outcrop sections plus special spot samples from two or three additional outcrops; I (for *intensive*) indicates that more than four outcrop sections were studied as well as two or more spot samples. An average of more than 20 samples were processed from each outcrop section. Diagonally cross-hatched bars indicate shale. Stippled bars indicate limestone. Vertically cross-hatched bars indicate sandstone.

(1) Based on three limestone samples.
(2) All red shale samples were barren. Average yield for non-red samples was 9.6 conodonts per kilo with 60 per cent of the samples yielding.
(3) Only identifiable specimens are recorded on the graph. Seventy-five percent of all Ste. Genevieve samples contained conodonts but thirty-eight percent of these samples were rounded specimens which were not identifiable.
(4) At Alton, Illinois the upper St. Louis yielded an average of 10 conodonts per kilo whereas the lower St. Louis yielded an average of only 3 conodonts per kilo.


FORMATIONS
KINKAID
DEGONIA
CLORE
PALESTINE
MENARD
WALTERSBURG
VIENNA
TAR SPRINGS
GLEN DEAN
HARDINSBURG
GOLCONDA
CYPRESS
PAINT CREEK
YANKEETOWN
RENAULT
AUX VASES
STE. GENEVIEVE
ST. LOUIS
SALEM
WARSAW
KEOKUK
BURLINGTON
FERN GLEN
SEDALIA
CHOUTEAU
HANNIBAL
GLEN PARK
LOUISIANA
SAVERTON
GRASSY CREEK
SYLAMORE
R = red
C = coal
C,R
R
R
R
R
R
R
Conodonts per kilogram
10 20 30 40 50+
Shale
Limestone
(2)
(4)
200
FEET
100
0
Sandstone
% of samples with conodonts
10 30 50 70 80+
(3)
Amt. of study
R S I
(1)



TEXT-FIG. 2—Graphs showing comparative occurrences of conodonts in shale and limestone in each series. Stippled bars indicate limestone. Diagonally cross-hatched bars indicate shale. (1) Number of samples insufficient to establish a reliable average.

cluded differing lithologies. Recent and future study will correct this situation and further diversify sampling.

ABUNDANCE OF CONODONTS IN THE CHESTER SERIES

Limestones are the most reliable and productive sources of conodonts in the Chester Series. Conodonts were found in more than 400 limestone samples from virtually every kind of limestone in the series. More than 90 percent of the limestone samples from the Kinkaid, Glen Dean and Renault Formations contain conodonts and they average about 20 conodonts per kilogram of sample. The maximum yield from a Chester sample was 175 specimens per kilogram from a single sample in the Glen Dean. Maximum yields from the Kinkaid and Renault were 140 and 105 respectively.

Chester shales are not nearly so productive as the limestones. Hundreds of samples show that conodonts are common in both calcareous and noncalcareous shales of green, buff, gray, or brown color. They are not found in red shales of Chester age. Red shales from three formations represented by 55 samples yielded no conodonts, even though important numbers of specimens were found in other shale and limestone samples from the same formations at the same localities. For example, the Paint Creek Formation, which contains considerable thicknesses of red shale, yielded no conodonts from the red beds but yielded an average of 9 specimens per kilogram of sample in 60 percent of the samples from nonred strata. The apparent explanation is that red strata in the Chester Series represent either nonmarine or abnormal marine deposits.

The highest average yields among Chester shales came from those of the Kinkaid Formation which contained an average of 26 specimens per kilogram of sample even though only 56 percent of the shale samples were productive. Less productive are the shales of the Menard, Glen Dean, and Golconda which produced an average of 7 conodonts per kilo. Sixty-eight percent of the Menard shale samples contained conodonts whereas 63 percent of the Glen Dean and 47 percent of the Golconda were productive. Conodonts on the average are uncommon in the shales of the Renault and Paint Creek and are rare in shales of the Clore.

Sandstones of the Chester Series appear to be relatively barren although our conclusions are based on few samples. Since many of the Chester sandstones are channel sands that were deposited rapidly and commonly represent nonmarine or brackish water deposits, the presence of conodonts in them was not expected.

ABUNDANCE OF CONODONTS IN THE VALMEYER SERIES

Although samples from the Valmeyer Series rarely contain conodonts in abundance, the fossils are distributed fairly uniformly throughout the section. For example, samples from the Ste. Genevieve Formation contain an average of only 2 or 3 conodonts per kilogram (in no sample were there as many as 25 specimens), but they are present in 75 percent of the samples. About half of the Ste. Genevieve specimens came from sandy oolitic limestone and were abraded to the degree that a large proportion were unidentifiable. Despite this disadvantage, 49 percent of all samples taken from the Ste. Genevieve contain forms not found in older formations.

Seventy percent of the samples from the

St. Louis Formation yield an average of 7 conodonts per kilogram of sample. There is a notable irregularity in distribution of the fossils in the Alton, Illinois area. There beds above the conspicuous breccia near the middle of the formation yield an average of 10 conodonts per kilo, but those below yield only 3 per kilo.

The Salem Limestone is even more consistent than the St. Louis because 75 percent of all samples carry conodonts, even though the average yield per kilogram is only seven specimens. Six percent of the samples yield more than 25 conodonts per kilogram. Figures for the Warsaw are roughly comparable.

Study of conodonts from the Keokuk Formation is in early stages and little detailed information is available concerning that formation. The faunas of the Burlington are fairly well known, however, and conodonts are rather uncommon as well as sporadic in distribution. The faunas of the Fern Glen Formation give average yields of 11 or 12 specimens per kilogram but occur in only 50 percent of the samples. The Sedalia Formation of Illinois (as differentiated from the Sedalia of Missouri) is the oldest formation in the Valmeyer and is the most prolific in the entire series. Although the formation is of limited geographic extent and is thin (generally less than 10 feet), it yields an average of 20 conodonts per kilogram with remarkable reliability. Seventy percent of all samples contained conodonts.

ABUNDANCE OF CONODONTS IN THE KINDERHOOK AND UPPER DEVONIAN SERIES

The most notable occurrences of conodonts in the pre-Valmeyer formations are found in the Saverton Shale of western Illinois and northeastern Missouri. Many Saverton samples yield 75 to 100 conodonts per kilogram although beds containing great numbers of the fossils are commonly interspaced with beds carrying relatively few. Nearly every sample contains significant numbers of specimens, however. Commonly, great numbers of specimens occur in thin beds that also contain rounded sand grains, iron stain and pyrite, which may indicate a lapse of clay deposition but a continuance of conodont accumulation. Faunas from such zones are virtually unsorted and contain complete suites of growth stages for nearly every species present. Shales from the Saverton sludge readily in Stoddard's solvent and can be wet screened at the rate of 3 to 5 kilograms per hour.

The Hannibal Formation yields large numbers of conodonts, but they are mainly from beds high in clay and low in silt. Some beds in the formation are nearly as prolific as those of the Saverton, but there are many beds in the formation that contain no conodonts. The Hannibal averages 40 specimens per kilogram and 70 percent of the samples yield conodonts.

The Chouteau Limestone contains fairly large numbers of specimens and, although yields are never spectacular, they are evenly distributed throughout the formation.

Notable, due to the low numbers of specimens they have produced, are the Glen Park, Louisiana, and Grassy Creek Formations. The Glen Park is quite variable in lithology and consists of oolitic limestone, limestone conglomerate, calcareous siltstone, dolomitic limestone, and silty shale. Such lithologies and lateral variability indicate rather rapid deposition and may explain the low numbers of conodonts collected.

The Louisiana is a pure lithographic limestone mottled with dolomite and represents a very distinctive lithology. The low numbers of conodonts may be either the result of rapid chemical precipitation of the limestone or, less likely, of a peculiar environment unfavorable to conodonts. The McCraney Limestone of southeastern Iowa and western Illinois, although correlative to the Chouteau, is nearly identical in lithology to the Louisiana. Like the Louisiana it contains few conodonts.

Only one "black" fissile shale, the Grassy Creek, was included in our study. Branson and Mehl (1934) reported an extensive conodont fauna from the formation, but at the time of their study the overlying green-gray Saverton Shale was not differentiated and both gray and black shales were included under the term Grassy Creek. At present the Saverton is recognized by both Illinois and Missouri State Geological Surveys as a distinct and extensive formation, and the Branson and Mehl faunas came principally from it (Mehl, personal communication,

Aug. 1956). Our samples of the Grassy Creek (restricted) indicate that occurrences are very sporadic and yield an average of less than five conodonts per kilogram of sample.

The oldest formation we have examined, and the only sandstone that yielded appreciable numbers of conodonts, is the Sylamore Sandstone. It overlies beds ranging in age from Middle Devonian to Ordovician. At the sections we examined, the Sylamore was never more than a few inches thick but it contained conodonts in more than 50 percent of the samples and in some cases in great numbers.

SUMMARY

Conodonts are widely distributed both stratigraphically and geographically in rocks of Devonian and Mississippian age in the upper Mississippi Valley. The stratigraphic distribution of conodonts and the relationship of their occurrence to lithology indicate that conodonts were continuously present and rather uniformly abundant in the seas during Devonian-Mississippian time. Accordingly, the rate of deposition of sediments may be the most important factor governing conodont occurrence.

In sandstones, such as those of the Chester Series, sedimentation rates were high and the sandstones are virtually barren of conodonts. Kinderhook shales, on the other hand, are the result of irregular rates of clay and silt deposition, and contain many zones of very high conodont yields interspaced with zones of low or no yield. In most of the limestones, stratigraphic distribution of conodonts is much more uniform than in shale samples, but average yields are lower. Most limestones thus appear to be the result of moderately slow, but rather constant, deposition. The paucity of conodonts in the Louisiana, McCraney, and Glen Park Limestones may indicate that those formations are the result of rapid deposition.

Bottom environment appears to be a minor factor in the distribution of conodonts in marine rocks. Rexroad (1958) has shown by study of the Glen Dean that the nature of the conodont fauna is not significantly affected by lithologic variations. Conodonts apparently do not occur in nonmarine or brackish-water sediments.

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NEW CRICETID RODENTS FROM THE NIOBRARA RIVER FAUNA, NEBRASKA

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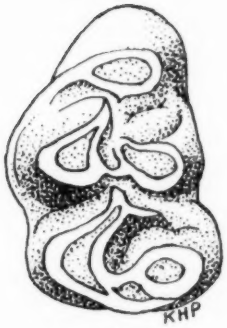
In 1936, Professor R. A. Stirton collected small fossil mammals from the Late Miocene deposits containing the Niobrara River fauna on the Niobrara Game Preserve, Cherry County, Nebraska. The specimens were taken on the quarter section line between the northwest and southwest quarters of Section 24, T34N, R26W, at a spot 1½ miles northeast of the headquarters of the Niobrara Game Preserve.

These specimens were made available to me for study by the University of California Museum of Paleontology while I was studying the phylogeny of the cricetid rodents. I am particularly grateful to Dr. Stirton for placing these at my disposal.



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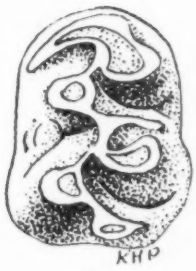

B

TEXT-FIG. *1A*—Occlusal view of left M^1 of type specimen of *Miochomys niobrariensis*, U. C. No. 36103, ×20.

TEXT-FIG. *1B*—Occlusal view of left M_1 of type specimen of *Peromyscus kelloggae*, U. C. No. 36105, ×20.

SYSTEMATIC DESCRIPTION

Class MAMMALIA
Order RODENTIA
Family CRICETIDAE

MIOCHOMYS NIOBRARIENSIS Hoffmeister, n. gen. and n. sp.
Text-fig. 1A

Holotype.—University of California Museum of Paleontology, No. 36103; part of a left maxilla bearing M^1.

Age and locality.—Barstovian, Late Miocene; Niobrara River fauna. Collected in 1936 at 1½ mi. NE headquarters, Niobrara Game Preserve, on quarter section line between NW and SW quarters of Sec. 24, T34N, R26W, Cherry County, Nebraska. Found in a gray, sandy formation with green clay and sandstone members, but mostly loose sand. Univ. California paleontological locality No. V-3218.

Diagnosis.—A cricetid rodent in which the cheek teeth have both the lingual and labial cusps elevated and of nearly the same height; cingular portion of the cusps wear least; reentrant angles of two sides of tooth nearly opposite and nearly continuous as transverse valleys across low central axis; the two transverse valleys across tooth give M^1 the appearance of three separate segments, namely (1) anterocone, (2) protocone-paracone, (3) hypocone-metacone (for terminology, see Hoffmeister, 1951:11); anterocone tends to be isolated from other cusps; mesoloph very weakly developed, but extending almost to cingulum; posteroloph apparently present, but, if so, weakly developed and fusing with posterior border of metacone.

Maxilla.—The ventral two-thirds of the left infraorbital plate and that portion of the maxilla bearing M^{1-2} are preserved. The anterior border of the infraorbital plate projects increasingly anteriad as it ascends dorsally, and in this detail resembles the plate in *Oryzomys* more than that of any other Nearctic genus. The anterior border of the plate is only slightly more medial than its posterior border, and if the structure is similar otherwise to Recent forms, this would result in a wide infraorbital fissure. The outer surface of the plate is more concave than in other forms, being similar to *Oryzomys* in this respect. No tubercle or fossa is present ventral to the infraorbital plate for attachment of *M. masseter superficialis*. Probably this muscle was weakly developed; it did not necessarily attach elsewhere. The absence of this tubercle is quite in distinction to the condition in *Reithrodontomys* (subgenus *Reithrodontomys*), *Reithrodontomys* (subgenus *Aporodon*), and *Baiomys*. The first molar is relatively farther posterior, in relation to the infraorbital plate, than in other Recent genera of Nearctic cricetid rodents.

Measurements.—All are in millimeters, of M^1 unless otherwise specified, and taken with an ocular micrometer: greatest length

of crown, 2.00; greatest length of occlusal surface, 1.70; greatest width of crown across protocone-paracone, 1.22; greatest width of crown across hypocone-metacone, 1.22; distance from posterior occlusal surface of anterocone to anterior border of tooth, .51; width of infraorbital plate, 2.45.

Comparisons.—The genus *Miochomys* differs from the genus *Onychomys* as follows: mesoloph present, but small; anterocone single rather than trifid or bifid and slightly higher; posteroloph weakly developed rather than absent; protocone more nearly opposite paracone; cusps not quite as high; infraorbital plate broader and ascending more anteriad; infraorbital foramen probably wider.

Miochomys differs from Upper Miocene *Peromyscus* (species *longidens*) as follows: transverse valleys continuous between reentrant angles; longitudinal axis of occlusal surface low; cusps on lingual side as high as on labial side, rather than lower. *Miochomys niobrariensis* differs from Recent species of *Peromyscus* in much the same way as it does from *Peromyscus longidens*, although the mesoloph is variable in Recent forms, but when present is always more prominent.

Miochomys differs from *Eumys*, *Leidymys*, and *Paciculus* as follows: reentrant angles more transverse, forming transverse valleys; posteroloph becomes indistinctly fused with metacone, or nearly so, rather than remaining as a distinct, separate loph; anterocone separated more from protocone; mesoloph much more weakly developed.

Remarks.—The genus *Miochomys* seems closely allied with the grasshopper mice of the genus *Onychomys*. This relationship is particularly well shown by the high cusps on the lingual side of the tooth and the two transverse valleys between the reentrant angles. This arrangement results in a sheering tooth adapted for a carnivorous or insectivorous type of diet, as found in Recent species of *Onychomys*. The features in which *Miochomys* differs from *Onychomys* are noted above. It is believed that *Miochomys* was probably insectivorous.

In some features, *Miochomys* may be intermediate between *Onychomys* and *Peromyscus*. These would be the presence of a posteroloph, although greatly reduced, a less nearly complete union of reentrant angles to form transverse valleys than in *Onychomys*, and the presence of a mesoloph in an otherwise *Onychomys*-like tooth with high lingual cusps.

The name *Miochomys* is proposed in allusion to the fact that this form is related to *Onychomys* and is found in the Miocene. The specific name is for the local fauna

Class MAMMALIA
Order RODENTIA
Family CRICETIDAE
PEROMYSCUS KELLOGGAE
Hoffmeister, n. sp.
Text-fig. 1B

Holotype.—University of California Museum of Paleontology, No. 36105, part of a left mandible with M_1.

Age and locality.—Barstovian, Late Miocene; Niobrara River fauna. Collected in 1936 at 1½ mi. NE headquarters, Niobrara Game Preserve, on quarter section line between NW and SW quarters of Sec. 24, T34N, R26W, Cherry County, Nebraska. Found in a gray, sandy formation with green clay and sandstone members, but mostly loose sand. Univ. California paleontological locality No. V-3218.

Referred specimen.—University of California Museum of Paleontology, No. 36158, a left lower jaw with incisor but lacking cheek teeth and the angle. From same locality as the holotype.

Diagnosis.—A species of *Peromyscus* with a small anteroconid, distinctive cuspid on posterolophid, and reentrant angle posterior to entoconid not directed as much anteriorly at apex as in most *Peromyscus*. Diagnostically different from other species of *Peromyscus* from the Upper Miocene in that protoconid arm or mesolophid extends transversely to cingulum; much smaller size.

Measurements.—All are in millimeters, of M_1 unless otherwise specified, and taken with an ocular micrometer. For the type specimen: greatest length of crown, 1.50; greatest width across protoconid, 1.06; greatest width across hypoconid, 1.16; height of jaw at diastema and immediately in front of mental foramen, 2.35; width (thickness) of lower left incisor, .59.

For specimen No. 36158: height of jaw at diastema and immediately in front of mental foramen, 2.40; approximate width

(thickness) of lower left incisor, .59; approximate alveolar length of lower molars, based on root remnants and alveoli only, 3.85; for individual teeth: M_1, 1.25; M_2, 1.20; M_3, 1.10.

Comparisons.—Differs from Recent species of *Peromyscus* as regards M_1 in small anteroconid; strong posterolophid with a small but distinctive cuspid; reentrant angle posterior to entoconid not directed as much anteriorly at apex; mesolophid not as closely associated with the entoconid, and may actually be the posterior arm of the protoconid (thus showing some similarity to *Eumys*).

Differs from *Peromyscus longidens* from the Barstow in mesolophid extending to cingulum; smaller size, with length of M_1 less than M_2 of *P. longidens* and M_1 15 percent shorter than same tooth in *longidens*.

Remarks.—*Peromyscus kelloggae* is close in pattern of M_1 to the Barstow *Peromyscus longidens*. In some features, these two species are intermediate between the earlier cricetid genera and the later species of *Peromyscus*. Nevertheless, the species *kelloggae* seems referable to one of the following Recent subgenera: *Peromyscus*, subgenus *Peromyscus; Peromyscus*, subgenus *Ochrotomys;* or *Reithrodontomys*, subgenus *Aporodon*. In *Aporodon*, the mesolophid fuses generally along its posterior margin with the entoconid. This is not the case in *P. kelloggae*. The pattern of M_1 in *kelloggae* resembles that of *Ochrotomys* and there are no good reasons for not referring this species to the subgenus *Ochrotomys*. Since M_1 in *kelloggae* so closely resembles the pattern of M_1 in *Peromyscus longidens*, which on the basis of upper as well as lower teeth seems best referred to the subgenus *Peromyscus*, *P. kelloggae* likewise is referred to *Peromyscus*.

The nearly complete jaw, No. 36158, which is toothless except for the incisor, is referred to *P. kelloggae*. The shape of the jaw is almost identical with that of *Peromyscus truei* among Recent species. The relationship of the coronoid and condyloid processes are essentially the same as in *P. truei*, although the condyloid bar is slightly longer and narrower.

The lower incisor in each specimen shows no sign of grooving.

The name *kelloggae* is proposed in recognition of the pioneer work of Miss Louise Kellogg on the rodent material in the paleontological collections of the University of California.

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JOURNAL OF PALEONTOLOGY, V. 33, NO. 4 P. 700–701, JULY 1959

NOMENCLATURAL NOTES

WILSONITES, NEW NAME FOR *WILSONIA* KOSANKE, 1950

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Harold N. Moldenke has called my attention to the fact that *Wilsonia* Kosanke, 1950 (Pennsylvanian spores of Illinois and their use in correlation: Illinois State Geol. Survey Bull. 74, p. 54) is a homonym, being preoccupied by *Wilsonia* R. Br., Prod. 490. 1810 (Convolvulaceae); *Wilsonia* Raf., Specchio 1: 157. 1814 (Epacridaceae); and *Wilsonia* Hook., Bot. Misc. 1: 172. 1829 (Verbenaceae). I therefore propose *Wilsonites* Kosanke, a new name for *Wilsonia* Kosanke, 1950. Thus, the binomial of the type is now *Wilsonites vesicatus* (Kosanke) Kosanke. *Wilsonia delicata* Kosanke 1950, p. 54–55, becomes *Wilsonites delicatus* (Kosanke) Kosanke.

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FUSULINA PSEUDOCHOMATATA, NEW NAME FOR *FUSULINA VALIDA* STEWART

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1958. *Fusulina valida* Stewart, Jour. Paleontology, v. 32, p. 1062, pl. 135, figs. 6–11 (preoccupied by *Fusulina* (*Schellwienia*) *valida* Lee, 1927, Palaeontologia Sinica, v. IV, Ser. B., Fasc. 1, p. 69–71, pl. VIII, figs. 1–5,10).

My thanks are due Garner L. Wilde of Midland, Texas, for calling my attention to the above homonymity.

J. S. Lee in 1927 included (*Girtyina*), (*Schellwienia*), and (*Schwagerina*) as subgenera under the genus *Fusulina* Fischer de Waldheim. At that time he erected the new species *Fusulina* (*Schellwienia*) *valida* from *Fusulina vulgaris* var. *fusiformis* Schellwien-Dyhrenfurth. At present, *Fusulina* (*Schellwienia*) *valida* Lee falls under the genus *Schwagerina* and is *Schwagerina fusiformis* (Schellwien) of authors. Even though the name *Fusulina valida* is not at present a valid name for any given species of fusulinid, it cannot be reused under the genus *Fusulina*.

Hence, the name *Fusulina pseudochomatata* is here given to apply to the holotype and all specimens called *Fusulina valida* from the upper Strawn of Central Texas. The name pseudochomatata seems appropriate since the species is characterized by the bulb-shaped features of that name.

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POLYPORA MCNAIRI, NEW NAME FOR *POLYPORA BASSLERI* MCNAIR, PREOCCUPIED

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Recently, in reviewing some Paleozoic *Polyporas* it came to my attention that *Polypora bassleri* McNair 1942 (Upper Devonian Bryozoa, Jour. Paleontology, v. 16) is preoccupied by *Polypora bassleri* Condra 1902 (New Bryozoa from the Coal Measures of Nebraska, Am. Geol., v. 30). Several letters to Dr. McNair pointing this out failed to draw any response.

For this reason, I have taken it upon myself to rename the form *Polypora mcnairi*.

JOURNAL OF PALEONTOLOGY, V. 33, NO. 4, P. 702–726, JULY 1959

SOCIETY RECORDS AND ACTIVITIES

REPORTS AND MINUTES OF THE THIRTY-THIRD ANNUAL MEETING OF THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

The thirty-third annual meeting of the Society of Economic Paleontologists and Mineralogists was held in the Dallas Memorial Auditorium, Dallas, Texas, March 16–19, 1959, in conjunction with the annual meeting of The American Association of Petroleum Geologists.

The Society's program consisted of papers on Concepts of Stratigraphic Classification and Correlation; Paleontology and Stratigraphy; and Sedimentary Minerology and Petrology.

At a joint session on Tuesday morning, March 17, Gordon Rittenhouse, President of the S.E.P.M., presented the following address:

THERE IS A REASON

Mr. Chairman, fellow members of S.E.P.M and A.A.P.G, and guests, if I were a preacher instead of a geologist, I might take for my text today the words "There is a reason." I am not a preacher, of course, but as some of you know, I have been somewhat of a missionary within our profession for a way of thinking about rocks—or if you wish, a philosophy about how to look at rocks. This philosophy or way of thinking is not new—certainly it is not original with me but antidates by far my entrance into the field of geology some 30 years ago.

What is this way of thinking—this philosophy? It is based on the assumption that rocks as they occur today did not just happen, but that there is a reason for their being what they are and where they are. What rocks are and where they are is due to a combination of physical, chemical, and biological factors that have acted through time according to definite laws. These factors have left their imprints on the rock in varying degrees and, from these imprints or clues, the past history of the rock may be reconstructed with varying degrees of success. This reconstruction of the total history of the rock is to me of paramount importance. To do it one needs not only to observe and ask "why"; one must believe "There is a reason."

This may seem quite simple—something that we all do—and therefore you may be wondering why I am talking about it today. It is simple—but it certainly is *not* something we all do.

Let me illustrate this with two examples. I keep on my desk a piece of core that I call my "Separator of Men from Boys." I have given many budding geologists fresh from more than a score of universities a hand lens and knife and asked them to study this core for a few minutes and then to describe it, to give the rock a name, and to indicate what geological history can be deduced from it. I have found few "Men" and many "Boys." Less than half recognized that information about the relief, the climate, and the kind and age of rocks in the source area can be deduced from the kind and size of pebbles, or that size, sorting, and rounding of the pebbles suggest a relatively short distance of transport and deposition under fluvial conditions, probably in an alluvial fan.

Fewer than one in ten recognized that the orientation of the pebbles indicates that the beds are almost vertical, or that low porosity, close packing, and the kinds and number of contacts between pebbles indicate extensive post-depositional modification. Most of those young geologists were not asking themselves "What properties does this rock have that will tell where it came from, how and under what environmental conditions was it formed, and how has it been changed since it was deposited?" Nor were they saying "There is a reason" why it is like it is today.

As a second example, I might point to descriptions of measured sections. In publications these commonly read "sandstone, brown, fine-grained, cross-bedded, 14 feet," and I have no reason to believe the descriptions are more extensive in many field notebooks. Here we have major lithology, color, size of grain, and the presence of a primary structure. For distinguishing this bed from

those above and below, or for comparing it or the beds in a sequence, with beds in another measured section this may appear to be adequate, in fact, may appear to be a first very necessary step. But is it adequate? From the terms "sandstone" and "fine-grained" it may be inferred that the agent of deposition was a current of moderate velocity. What kind of current and what was its direction of flow? I submit that these are important questions to answer, since the answers may bear on selection of where to measure the next section or how the lithologic variations between sections are to be explained. In our example, cross-bedding may be a useful clue. But what do we know from just the word "cross-bedded"? Our answer may come from the direction of dip of the cross-beds, their inclination, their thickness and lateral extent, and their relation to beds above and below.

I might follow this example further, using the lack of information on composition conveyed by the broad term "sandstone" and the lack of information on how much induration has occurred and what caused the induration. I hope, however, that I have made my point; namely, that it is common to overlook may clues that could be used in reconstructing the history of rocks because we are not wondering what they mean nor assuming that "There is a reason."

In looking at any rock we have some purpose—and a limited time in which to achieve that purpose. Therefore we cannot describe everything—we must be selective, observing or measuring those features of the rock that will permit us to accomplish our purpose. In making this selection we are guided by our past experience—and by our way of thinking about rocks.

When our objective is limited, such as in identifying a subsurface structural datum, our choice may be easy, because our past experience or that of others may indicate what to look for. Generally little thought is required to identify the datum—although much thought may be needed to interpret what the position of the datum means.

When our objective is broader, the choice may be more difficult, requiring a combination of past experience and a way of thinking about rocks. Thus in our "sandstone, brown, fine-grained. cross-bedded, 14 feet" example, reliance is being placed on past experience but this time with the *hope* of accomplishing the purpose, experience having shown that useful geological interpretations may be made in some cases if vertical and lateral variations in lithology are known. Outlining lithologic geometries may be a powerful tool, particularly in subsurface work—provided enough control points are available to define the geometry and provided we know what the geometry means when we have it. Commonly our control is not adequate, and how we interpolate between control points to outline the geometry will depend on our way of thinking about rocks.

All too often, past experience is substituted for thought—not made its partner. Because certain types of observations or measurements have contributed to the successful solution of problems in the past, they are selected and applied indiscriminately to new problems. Here we have one type of "shot gun" approach, based on a philosophy which, in effect, says "If we can make enough observations on enough rocks, put them in a machine and turn the crank, something useful may come out." To some, this is the "modern statistical approach" to geological problems. This maligns statistical methods—which can be valuable in geology—though not as a substitute for thinking. Since this approach does not reach the objective in a minimum of time, if at all, it is wasteful of time, manpower and money. I prefer the "There is a reason" philosophy.

In selection of features that may be significant in rocks, we are faced with ever increasing knowledge in geology and related sciences, and ever increasing specialization. In looking at rocks and at problems involving rocks there is an increasing tendency to look at specialized aspects of the rock, rather than at the rock as whole. The sands "belong" to one specialist; the clays, the carbonates, the isotopes, the trace elements and various fossil groups, to others. Specialization has great potentialities for our science, since it can lead to a better understanding of the physical, chemical, and biological factors that have made rocks what they are today. But it has great hazards as well. Let's not forget how the elephant appeared to the three blind men—like a wall, like a post, like a snake. Just as we need to consider the en-

HENRYK B. STENZEL
Honorary Membership

tire elephant, we need to consider the entire rock—putting each type of observation and deduction in its proper perspective.

With an increasing number of things to observe or measure, it becomes increasingly important to make the proper choice—the choice that will permit us to reach our objective in the time available. To me the obvious procedure is to go from the simple to the complex, from the rapid to the slow, from the less expensive to the more expensive. In general, but not always, this will mean going from the large to the small, from the visible to the invisible, from the direct to the indirect. There is no magic formula, no "gimmick," that will indicate what to look for or when. This will depend on the problem, the purpose, the time, the material available, and the way one thinks about rocks. Because I am firmly convinced that what rocks are and where they are has resulted from a combination of physical, chemical, and biologic factors that have acted through time according to definite laws, and that those factors have left their imprints on the rock in varying degrees, I believe that as we study rocks we should observe, ask "why" and remember "There is a reason." Thank you.

Also, at the joint session on Tuesday morning, President Rittenhouse presented an honorary membership award to Henryk B. Stenzel, a past-president of the Society. The award consists of a certificate and the receipt of both of our *Journals* for life.

Dr. Stenzel was born February 7, 1899, in Pabianice, Poland. His formal education was received at Schlesische Friedrich Wilhelms Universitaet, at Breslau, Germany, where he was granted a Ph.D. degree in 1922. For two years after his graduation, he was an assistant at the Geological Insitute of the University at Breslau. He then came to the United States and to the Agricultural and Mechanical College of Texas where he was an instructor and later was promoted to assistant professor. He remained here from 1925 to 1934, at which time he accepted a position with the Bureau of Economic Geology at the University of Texas, Austin, serving in this capacity for twenty years. For seven years during this period he also taught geology at the University, holding the title of "Professor of Geology." From 1954 to 1957 he was "Special Professor of Geology" at the University of Houston.

Dr. Stenzel's publications include articles on tectonics of intrusive granite bodies, areal geology, tertiary stratigraphy and paleontology, decapod crustacea, and fossil ostreidae. He holds membership in many professional organizations, among them: Geological Society of America (Fellow), Paleontological Society (member, president in 1955), American Association of Petroleum Geologists (member, served on Business Committee, Medal Award Committee, and Research Committee), and the Malacological Society of London.

In 1929 Dr. Stenzel joined the S.E.P.M. He served as its Secretary-Treasurer from 1939 until 1949 when he was elected President of the Society.

Dr. Patrick H. Monaghan was the recipient of the first award to be presented by the S.E.P.M. for a "Best Paper at the Convention." President Rittenhouse presented him with a book of his choice, *The Oceans*, for his

paper, "The Solubility of $CaCO_3$ in Salt Water," presented at the 32nd Annual Meeting of the Society in Los Angeles. His paper was judged, by a committee of five, on content, organization, originality, and presentation.

Now senior research engineer, production research division of the Humble Oil and Refining Company of Houston, Texas, Dr. Monaghan was born July 25, 1922, in Memphis, Tennessee. He received a B.S. degree in chemical engineering from Louisiana Polytechnic Institute in 1943; in 1949 he was awarded a master's degree in chemistry from Louisiana State University and a Ph.D. degree was conferred upon him by the same University in 1950.

Dr. Monaghan was a Radar Officer with the U. S. Marine Corps from 1943 to 1946, at which time, upon his discharge, he became associated with the Sperry Gyroscope Company as field engineer. In 1947 he entered L.S.U. Graduate School to work toward his doctorate in chemistry. He has been employed by Humble since 1950.

A number of chemical publications by Dr. Monaghan have appeared in *Analytical Chemistry*. In addition to the paper which is the subject for this award, Dr. Monaghan published an article in the S.E.P.M.'s Quarterly Journal, the *Journal of Sedimentary Petrology*, entitled, "The Origin of Calcareous Ooliths" (Volume 26, Number 3).

Dr. Monaghan became an associate member of the S.E.P.M. in 1955. He is also a member of the American Chemical Society and The American Institute of Mining, Metallurgical and Petroleum Engineers.

In addition to the above awards, S.E.P.M. Research Committee Chairman, Grover E. Murray, presented the Society's Award for the Best Paper for 1957 in the *Journal of Paleontology* to Helen Tappan and Alfred R. Loeblich, Jr., husband-wife team, for their paper entitled, "Correlation of the Gulf and Atlantic Coastal Plain Paleocene and Lower Eocene Formations by Means of Planktonic Foraminifera," which appeared in the November issue, Volume 31, Number 6. Dr. Murray also presented the award for the Best Paper for 1957 in the *Journal of Sedimentary Petrology* to Raymond Siever, for his paper entitled, "Pennsylvanian Sandstones of the Eastern Interior Coal Basin,"

DR. PATRICK H. MONAGHAN
Best Paper at 1958
Los Angeles Convention

published in the September issue, Volume 27, Number 3.

The Best Paper Awards are the fifth to be presented by the S.E.P.M. They consist of a certificate given to the author whose paper, appearing in the Journals during the second preceding year, is judged by the Research Committee to be the most outstanding contribution of the year.

Born in Birmingham, Alabama, on August 15, 1914, Dr. Loeblich attended Oklahoma University where be obtained both B.S and M.S. degrees in geology (1937 and 1938 respectively). A year after receiving his Ph.D. degree from the University of Chicago, in 1941, Dr. Loeblich entered the U. S. Army as a Field Artillery Captain, serving in the New Hebrides, Okinawa, and Philippine Islands. Upon his discharge in 1946, Dr. Loeblich became associate curator of Invertebrate Paleontology and Paleobotany at the U. S. National Museum in Washington, D. C., where he remained until 1957 when he accepted his present position at California Research Corporation.

MR. AND MRS. ALFRED R. LOEBLICH, JR.

BEST PAPER AWARD, 1957
Journal of Paleontology

Loeblich has published over 50 articles on foraminiferal faunas, morphology and taxonomy, bryozoa, and stratigraphy in the *Journal of Paleontology, A.A.P.G. Bulletin, Micropaleontology, Bulletin of American Paleontology, U. S. National Museum Bulletin,* and many others.

In addition to his membership in the S.E.P.M., Dr. Loeblich is a member of The American Association of Petroleum Geologists and the Paleontological Society. He is a fellow in the Geological Society of America, Cushman Foundation for Foraminiferal Research, and the Washington Academy of Science. He is also a member of numerous foreign professional organizations, Sigma Xi, and Phi Beta Kappa.

Dr. Loeblich was appointed a member of S.E.P.M.'s Research Committee in 1957, serving as vice-chairman for that year. His three-year term on this committee will expire with the annual meeting in Dallas, in 1959.

Mrs. Alfred R. Loeblich (who publishes under the name of Helen Tappan) was born in Norman, Oklahoma, October 12, 1917. She, also, received B.S. and M.S. degrees in geology from the University of Oklahoma, and in 1942 was awarded a Ph.D. degree from the University of Chicago.

For one year prior to her connection with the U. S. Geological Survey in 1943, Mrs. Loeblich was an instructor in geology at Tulane University. In 1952 she was engaged in the study and collection of foraminifera in Western Europe (John Simon Guggenheim Foundation). From 1954–1957, just prior to her California connections, Mrs. Loeblich was an Honorary Research Associate in Paleontology at the Smithsonian Institution in Washington, D. C.

Mrs. Loeblich's general field of publication is foraminiferal faunas, morphology, classification and correlation. In addition to many articles in the *Journal of Paleontology,* she has published in the *Bulletin of American Paleontology, Journal of the Washington Academy of Science, U. S. National Museum Bulletin, Micropaleontologist,* and others.

Mrs. Loeblich is a fellow of the Geological Society of America, and a member of the Paleontological Society and the Cushman Foundation for Foraminiferal Research, in addition to membership in Sigma Xi and Phi Beta Kappa.

Raymond Siever, born September 14, 1923, in Chicago, Illinois, obtained B.S., M.S. and Ph.D. degrees in geology from the University of Chicago, the latter being conferred in 1950.

From 1943–1944, Mr. Siever was Research Assistant in the Coal Division for the Illinois Geological Survey. In 1944, and serving until 1946, Mr. Siever joined the photogrammetry unit of the U. S. Army Air Force, returning to the Illinois Survey in 1947 where he worked as assistant geologist, associate geologist, and geologist in the Coal Division. His work consisted of research in stratigraphy, coal and sedimentary petrology. From 1956 to 1957, when he became associate professor of geology at Harvard, Dr. Siever was National Science Foundation Senior Postdoctoral Fellow at Harvard University.

Dr. Siever's publications include articles on stratigraphy, sedimentary petrology,

coal petrology and structure. These have been published in the *Journal of Sedimentary Petrology, Bulletin of The American Association of Petroleum Geologists, Journal of Geology,* and *Illinois Geological Survey Reports.*

In addition to active membership in the S.E.P.M., Dr. Siever is a fellow of the Geological Society of America and The American Association for the Advancement of Science. He is a member of The American Association of Petroleum Geologists, Society of Economic Geologists, and Sigma Xi.

Dr. Siever was a member of the S.E.P.M. Research Committee from 1954 to 1957. He was chairman of the committee in 1956 and organized a Symposium presented at the Chicago, 1956, Convention entitled, "Directional Properties of Sedimentary Rocks."

RAYMOND SIEVER

BEST PAPER AWARD, 1957
Journal of Sedimentary Petrology

ANNUAL BUSINESS MEETING

The annual business session of the Society was called to order at 1:30 P.M., Tuesday, March 17, by Gordon Rittenhouse, President, who introduced the officers for the new year as follows: President, Samuel P. Ellison, Jr.; Vice-President, William J. Plumley; Secretary-Treasurer, John Imbrie; Editors of the *Journal of Paleontology,* M. L. Thompson and Charles W. Collinson; and Editor of the *Journal of Sedimentary Petrology,* Jack L. Hough.

It was moved, seconded, and carried that the minutes of the 1958 meeting be approved as published in the June, 1958, *Journal of Sedimentary Petrology* and the July, 1958, *Journal of Paleontology.*

The following reports were not presented at the Business Meeting, but instead they are printed in full below.

1. *Report of the Editors of the Journal of Paleontology (M. L. Thompson and C. W. Collinson).*—Volume 32 of the *Journal of Paleontology,* issued in conjunction with the Paleontological Society, contains 1170 pages of text and 148 plates. The S.E.P.M. portion of the volume contains 418 pages of text and 39 collotype plates of fossil illustrations. This represents a decrease of about 20 pages of text and two plates from the preceding volume. A larger part than in some previous volumes are without full tone plates. The subject matter covered concerns many fields of paleontology and can be referred in a general way to about 18 papers on megafossils and 12 papers on microfossils. Several papers can be defined as of both types, and a few papers concern mixed faunas. Paleoecology is the principal subject of four papers. Three papers deal mainly with biostatistics, and two are about biochemistry. Seventeen of the papers concern faunas of Paleozoic age, and 14 papers concern fossils of Mesozoic and Cenozoic ages. Many phyla of invertebrate animals, as well as some plants, are discussed to some degree in this volume.

Approximately the same number of unpublished manuscript pages and plates are on hand as were on hand at this time last year.

The editors wish to report that the comprehensive Index of the first 25 volumes of the *Journal of Paleontology* has come to a waiting stage until the species-genera portion of the Index has been completed. The subject-author portion of the Index is in manuscript form, and all of the species-gen-

S.E.P.M. COUNCIL, OUTGOING AND INCOMING

Sitting, left to right: Jack L. Hough, Editor *Journal of Sedimentary Petrology*; Raymond E. Peck, Secretary-Treasurer; Gordon Rittenhouse, President; W. M. Furnish, Vice-President; M. L. Thompson, Co-Editor *Journal of Paleontology*. Standing: William J. Plumley, Vice-President-Elect; Samuel P. Ellison, Jr., President-Elect; John Imbrie, Secretary-Treasurer-Elect; Charles W. Collinson, Co-Editor *Journal of Paleontology*.

era part is completed except for that from Volume 8.

We call attention to the fact that we have recently appointed associate editors in compliance with the recommendation given at the last meeting of the 1957 Council. Dr. Robert H. Shaver of the Indiana Geological Survey and Dr. Alan B. Shaw of the Shell Oil Company have generously consented to serve.

The Illinois Geological Survey furnished secretarial, technical, and financial assistance.

2. *Report of the Editor of the Journal of Sedimentary Petrology (Jack L. Hough).*—*The Journal of Sedimentary Petrology* was published in 1958 as Volume 28, Numbers 1 through 4. A summary of the contents is given in the accompanying table. The December issue, Number 4, was expanded by 16 pages in order to keep the wait for publication within a period of nine months. This temporary expansion was accomplished without exceeding the printing budget. The supply of unpublished manuscripts has increased somewhat during 1958, and it may be necessary to consider further expansion of size of the *Journal* during 1959. The national origins of the articles, notes, and discussions of Volume 28 were as follows:

United States	44
England	7
Canada	2
Wales	1
New Zealand	1
India	1
Netherlands	1
France	1
Czechoslovakia	1

As in the past nine years, the University of Illinois has provided the services of the Editor and of a part-time editorial assistant.

3. *Report of the Secretary-Treasurer (Raymond E. Peck).*—Income for 1958 was $1,845.14 more than in 1957 due largely to increase in income from subscriptions to *Journal of Paleontology* and *Journal of Sedimentary Petrology*—the price of *Journal of Sedimentary Petrology* was raised in 1958 and there was an increase in membership dues to persons taking this *Journal*.

Sale of back numbers amounted to $5,026.55. This is a primary source of income. This was a decrease from 1957 but subscriptions more than made up the difference.

Operating costs decreased $424.99 this

Journal of Sedimentary Petrology, Vol. 28, 1958

	Articles		Notes		Discussions		Reviews		S.E.P.M. Data[1] Pages	Advertising[2] Pages	Other[3] Pages	Total Pages
	No.	Pages	No.	Pages	No.	Pages	No.	Pages				
1. (Mar.)	14	105	1	3	—	—	—	—	15	1	4	128
2. (June)	10	94	4	7	1	2	7	5	14	1	5	128
3. (Sept.)	13	115	2	3	—	—	1	2	3	1	4	128
4. (Dec.)	11	121	1	2	2	5	—	—	—	2	8	144
Total	48	435	8	15	3	7	8	7	32	5	21	528

[1] Including announcements of meetings, programs, minutes of annual meeting, and membership list.
[2] Exclusive of advertisements on covers.
[3] "Other" includes title pages, index, errata, and announcements.

past year so we operated in the black to the extent of $2,270.13—an unusual circumstance in this day and age. I believe Dr. Ellison reported a profit of $907.46 last year.

Much credit for operating in the black is due to the editors of the *Journal of Paleontology*—their expense was $2,400 less than in 1957. Our thanks to Drs. Thompson and Collinson.

On December 31, 1958, our balance in the bank was $30,118.76—this included $8,062.37 in the Publication Fund. About half of this money in the Publication Fund will be used in paying for *Silica in Sediments*.—This has just been published and we hope the Society will make money on it.

Special Publications have continued to make money—all except the Index to the

MEMBERSHIP, MAILING, AND JOURNAL STATISTICS

	Dec. 31, 1958	*Dec. 31, 1957*	*Dec. 31, 1956*
1. S.E.P.M. Membership:			
Active Members	1094	1085	990
Associates	351	319	292
Correspondents	6	6	5
Honorary Members	5	3	3
	1456	1413	1290
2. *Journal of Paleontology* Mailing List:			
S.E.P.M. Active & Honorary Members	503	528	509
S.E.P.M. Associates	167	160	150
Subscribers	912	840	810
P.S. Members	649	638	624
	2231	2166	2093
3. *Journal of Sedimentary Petrology* Mailing List:			
S.E.P.M. Active & Honorary Members	726	721	677
S.E.P.M. Associates	220	207	184
S.E.P.M. Correspondents	6	6	5
S.E.P.M. Subscribers	997	979	890
	1949	1913	1756
4. Edition of *Journal of Paleontology*	2500	2400	2400
5. Edition of *Journal of Sedimentary Petrology*	2500	2400	2100
6. Number of Pages, *Journal of Paleontology*	1170	1190	1394
7. Number of Plates, *Journal of Paleontology*	148	150	146
8. Number of Pages, *Journal Sedimentary Petrology*	528	484	386
9. New Members	125	150	137
10. Transfers to active membership	24	49	41
11. Members and associates dropped for non-payment of dues (1/1/59)	65	49	17

The Council, Society of Economic Paleontologists and Mineralogists:

We have examined the accompanying balance sheet of Society of Economic Paleontologists and Mineralogists at December 31, 1958, and the related statement of income and surplus for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the statements mentioned above present fairly the financial position of Society of Economic Paleontologists and Mineralogists at December 31, 1958, and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

ARTHUR YOUNG & COMPANY

Tulsa, Oklahoma, January 19, 1959

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
BALANCE SHEET, DECEMBER 31, 1958

ASSETS

	Total	*General Fund*	*Publication Fund*
CURRENT ASSETS:			
Cash	$33,366.90	$25,304.53	$ 8,062.37
Savings account	2,823.01	2,823.01	—
Accounts receivable	295.40	230.40	65.00
Total current assets	$36,485.31	$28,357.94	$ 8,127.37
PUBLICATIONS:			
Journal of Paleontology:			
Issues prior to 1958—10,374 journals at $0.50 each (1,592 complete volumes)	$ 5,187.00	$ 5,187.00	$ —
Issues 1 to 6 of 1958—1,486 journals, at cost	2,984.63	2,984.63	—
Reprints in 1948, Volume 1, 1927—656 volumes, at cost	1,427.28	1,427.28	—
Journal of Sedimentary Petrology:			
Issues prior to 1958—4,069 journals at $0.50 each (1,103 complete volumes)	2,034.50	2,034.50	—
Issues 1 to 4 of 1958—2,068 journals, at cost	2,249.56	2,249.56	—
Special publications:			
Turbidity Currents, 108 copies, at cost	92.35	—	92.35
Recent Marine Sediments, 464 copies, at cost	957.46	—	957.46
Finding Ancient Shorelines, 86 copies, at cost	150.31	—	150.31
Regional Aspects of Carbonate Deposition, 327 copies, at cost	729.99	—	729.99
Journal of Sedimentary Petrology Index, 1,494 copies, at cost	862.49	—	862.49
Total publications	$16,675.57	$13,882.97	$ 2,792.60
FURNITURE AND FIXTURES (less reserve, $1,793.84)	$ 1.00	$ 1.00	$ —
DEFERRED CHARGES	$ 2,085.50	$ 873.05	$ 1,212.45
	$55,247.38	$43,114.96	$12,132.42

LIABILITIES AND SURPLUS

CURRENT LIABILITIES:			
Accounts payable	$ 4,011.13	$ 2,798.68	$ 1,212.45
Amount payable to Paleontological Society	3,371.57	3,371.57	—
Total current liabilities	$ 7,382.70	$ 6,170.25	$ 1,212.45
DEFERRED CREDITS:			
Subscriptions to Journals—net of portion to be received by Paleontological Society	$ 9,456.19	$ 9,456.19	$ —
Membership dues for 1959	9,071.00	9,071.00	—
Total deferred credits	$18,527.19	$18,527.19	$ —
SURPLUS, per accompanying statement	$29,337.49	$18,417.52	$10,919.97
	$55,247.38	$43,114.96	$12,132.42

Journal of Sedimentary Petrology. We have sold approximately 600 copies of it to date and have 1400 copies on hand. We are in the RED on it at present.

Mr. Dott is exploring the possibility of reprinting back numbers of both *Journals*. There is considerable call for those numbers which are out of print and we hope Mr. Dott will work out a deal that will continue to make money for the Society.

Membership shows a net gain of 43 persons. We added 125 new members last year

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
STATEMENT OF INCOME AND SURPLUS
YEAR ENDED DECEMBER 31, 1958

	Total	General Fund	Publication Fund
INCOME:			
Membership dues and subscriptions:			
Journals of Paleontology and Sedimentary Petrology	$ 4,777.00	$ 4,777.00	$ —
Journal of Paleontology	16,979.26	16,979.26	—
Journal of Sedimentary Petrology	13,145.54	13,145.54	—
	$34,901.80	$34,901.80	$ —
Sales of special publications:			
Turbidity Currents	$ 304.88	$ —	$ 304.88
Recent Marine Sediments	805.00	—	805.00
Finding Ancient Shorelines	472.70	—	472.70
Regional Aspects of Carbonate Deposition	911.30	—	911.30
Journal of Sedimentary Petrology Index	751.75	—	751.75
	$ 3,245.63	$ —	$ 3,245.63
Sales of back numbers:			
Journal of Paleontology, Volumes 1 to 31	$ 3,541.65	$ 3,541.65	$ —
Journal of Sedimentary Petrology	1,484.70	1,484.70	—
	$ 5,026.35	$ 5,026.35	$ —
Sales of plates	$ 538.66	$ 538.66	$ —
Advertising	$ 771.95	$ 686.95	$ 85.00
Donation from The American Association of Petroleum Geologists	$ 2,040.00	$ 2,040.00	$ —
Miscellaneous	$ 334.44	$ 334.44	$ —
	$46,858.83	$43,528.20	$ 3,330.63
Less portion of 1957 income accrued to Paleontological Society	3,427.71	3,427.71	—
	$43,431.12	$40,100.49	$ 3,330.63
COSTS AND EXPENSES:			
Cost of printing:			
Journal of Paleontology	$12,224.64	$12,224.64	$ —
Journal of Sedimentary Petrology	10,342.07	10,342.07	—
Journal of Sedimentary Petrology Index	1,179.98	—	1,179.98
	$23,746.69	$22,566.71	$ 1,179.98
Expenses:			
Clerical salaries	$ 7,755.00	$ 7,755.00	$ —
Office supplies	499.41	499.41	—
Postage and express	1,602.90	1,602.90	—
Office rent	2,000.00	2,000.00	—
Telephone	47.70	47.70	—
Audit fee	211.08	211.08	—
Payroll taxes	161.70	161.70	—
Miscellaneous	2,002.06	1,880.76	121.30
	$14,279.85	$14,158.55	$ 121.30
Adjustment for (increase) decrease in inventory of publications	$ (478.88)	$ (899.38)	$ 420.50
	$37,547.66	$35,825.88	$ 1,721.78
NET INCOME	$ 5,883.46	$ 4,274.61	$ 1,608.85
SURPLUS AT DECEMBER 31, 1957	23,454.03	14,142.91	9,311.12
SURPLUS AT DECEMBER 31, 1958	$29,337.49	$18,417.52	$10,919.97

as against 150 during 1947. We have dropped 44 members and 21 associates (total 65) for non-payment of dues. We dropped only 48 at the end of 1957.

We have lost 8 members through death during the past year.

The *Journal of Paleontology* mailing list has increased by 65 and the *Journal of Sedimentary Petrology* list by 36 during the past year.

4. *Report of the Research Committee (Grover E. Murray, Chairman).*—Membership of the committee, with terms ending at the annual meeting of each year as indicated, is:

1959	*1960*	*1961*
Virgil Barnes	H. A. Ireland	Heinz A. Lowenstam
R. V. Hollingsworth	Grover E. Murray	Arthur C. Munyan
A. R. Loeblich, Jr.	W. D. Pye	F. B. Van Houten
D. L. Inman	L. M. Cline	W. H. Akers
Stuart Levinson	S. G. Wissler	
Haydn H. Murray		

At the annual meeting in St. Louis on April 1, 1957, the committee selected "Concepts of Stratigraphic Classification and Correlation" as the topic for the 1959 annual symposium. W. C. Bell and L. L. Sloss were subsequently requested by chairman Murray to serve as co-chairmen in arranging this program. The symposium was organized during 1957–1958 as follows:

Session I

Presiding:
Grover E. Murray, Chairman of Research Committee
Arthur C. Munyan, Vice-Chairman

Hollis D. Hedberg (Gulf Oil Corporation, Pittsburgh, Pennsylvania), The Classification Controversy

John Rodgers (Yale University, New Haven, Connecticut), The Meaning of Correlation

Harry E. Wheeler (University of Washington, Seattle, Washington), Stratigraphic Units in time and Space.

Taras P. Storey (Husky Oil & Refining Limited, Calgary, Alberta, Canada) and J. R. Patterson (Amerada Petroleum Corporation, Calgary, Alberta, Canada), Stratigraphy-Traditional and Modern Concepts

Harold L. James (U.S.G.S., Washington, D. C.), Problems of Stratigraphy and Correlation of Precambrian Rocks with Particular Reference to the Lake Superior Region

A. D. Cumming, J. G. C. M. Fuller (Saskatchewan Department of Mineral Resources, Regina, Saskatchewan, Canada), and J. W. Porter (Canadian Superior Oil Company of California, Regina, Saskatchewan, Canada), Separation of Strata: Paleozoic Limestones of the Williston Basin

Session II

Presiding:
W. C. Bell, University of Texas
L. L. Sloss, Northwestern University

James L. Wilson (Shell Development Company, Houston, Texas), North American Cambro-Ordovician Biostratigraphy—Layer Cake Geology

Digby McLaren (Geological Survey of Canada, Ottawa, Ontario, Canada), The Role of Fossils in Defining Rock Units in the Devonian of Western and Arctic Canada

Keith Young (University of Texas, Austin, Texas), Techniques of Mollusk Zonation in the Texas Cretaceous

John A. Wilson (University of Texas, Austin, Texas), Mammalian Biostratigraphic Zones in the Continental Tertiary

C. O. Durham, Jr. (Louisiana State University, Baton Rouge, Louisiana), Provincial Time-Rock Nomenclature in the Gulf Cretaceous, Help or Hindrance?

Frank E. Lozo (Shell Development Company, Houston, Texas), Cyclic Correlation Units in the Texas Comanche Cretaceous

At the annual meeting in Los Angeles, March 10, 1958, the committee nominated Henryk B. Stenzel for Honorary Membership and recommended his election by the council. Subsequently this nomination was approved by the council and Dr. Stenzel was notified of his election by President Rittenhouse.

During 1958, the members of the committee were polled by mail regarding additional nominations for Honorary Membership and for Correspondents. Although no official nominations were made up to the time of the annual meeting, a list of prospective nominees was developed.

The best paper in the *Journal of Paleontology* for 1957 was selected, in a closely contested vote, to be that by Alfred R. Loeblich, Jr. and Helen Tappan entitled *Correlation of the Gulf and Atlantic Coastal Plain Paleocene and Lower Eocene Formations by Means of Planktonic Foraminifera*, November, 1957. The paper by Raymond Siever entitled *Pennsylvanian Sandstones of the Eastern Interior Coal Basin*, September, 1957, was selected as the best paper in the 1957 *Journal of Sedimentary Petrology*. Awards for these papers were presented to the respective authors by the chairman at the annual meeting in Dallas, Texas.

5. *Report of the Publications Committee* (*Samuel P. Ellison, Jr., Chairman*).—The Publications Committee, consisting of Samuel P. Ellison, Jr., Chairman (1959), Grover E. Murray, ex-officio member (1959), H. A, Ireland (1959), and T. H. van Andel (1960) considered one manuscript (*Modern Ecology*

of Foraminifera by Fred B. Phleger) during the past year. The manuscript was recommended as acceptable for a special publication provided the estimated possible sales would be profitable. It was finally decided that potential sales would not pay for the publication and the manuscript was released to the author.

6. *Report on the Earth Sciences Division of the National Research Council* (*John C. Frye, S.E.P.M. Representative*).—In accordance with its primary responsibility, the Division during the year rendered advisory services to federal agencies through ten committees and conducted one conference, all upon request of the government. About 80 scientists took part in this work.

The Arctic Sea Ice Conference was held February 24–27, 1958. The Division is preparing the papers and discussions for publication. The Committee on Waste Disposal, Advisory to the Atomic Energy Commission, published its report to the Reactor Development Division, AEC, as NAS-NRC Publication 519. During the year a meeting of this committee with representatives of the petroleum industry, as well as of AEC, was held in the Academy Building in Washington.

The Committee on the Glacial Map of the United States, east of the Rockies, has completed compilation of the map to be published by the Geological Society of America. A proof copy of the map was on display at the annual GSA meeting in November.

The Committee on Clay Minerals held its seventh annual conference in Washington, D. C., October, 1958, and the volume resulting from the sixth conference will be published by Pergamon Press in its monograph series on the earth sciences. The Committee on the Measurement of Geologic Time issued its last annual report covering the year 1954–55 as NAS-NRC Publication 500, and the Committee was discharged with thanks for having seen its work through to successful completio

Seven fellowship committees were active during the year; six groups screened applicants for awards under programs supported by the National Science Foundation, the Fulbright Act, and the Smith-Mundt Act, and one group met to evaluate candidates for a special award administered by the American Chemical Society.

The Division's Annual Meeting, attended by Francis J. Pettijohn, the outgoing S.E.P.M. Representative, formed part of the first general meeting of the entire membership of the National Research Council. The Research Council met as a body on March 30 and 31 and, after the introductory discussion of five major problems facing science in America and a survey of Academy-Research Council activities bearing on these problems, the membership divided itself into five sections for specific discussions. The findings will serve as guidance for continuing activities of the Council and of the Earth Sciences Division.

7. *Report on the American Geological Institute* (*Gordon Rittenhouse*).—S.E.P.M. was represented at meetings of the Board of Directors of A.G.I., held at the 1958 A.A.P.G.-S.E.P.M. and G.S.A. meetings in Los Angeles and St. Louis. Since many of the activities of the Institute are reviewed in *GeoTimes*, which is sent to all S.E.P.M. members, only the following items of special interest are reviewed here.

a. Finances remain a critical problem. Support of A.G.I. by the geological societies is on a year-to-year basis, and a proposed reduction in support by the G.S.A. has emphasized the uncertainty of even the present operations, which for 1959 will approximate $81,000. Grants aggregating $210,000 earmarked for the Earth Sciences Register, an International Abstract Survey, and Russian Translations have been obtained from the National Science Foundation. Additional grants, totaling $135,000, for geological abstracting, a visiting scientist program, and other projects are pending. The grants do not help support the general operations of A.G.I., which the Executive Director believes should be about $140,000–150,000 per year. No solution of the problem of providing A.G.I. a stable, predictable income has been reached.

b. In an effort to help the finances of A.G.I., Robert Karpinski of the Chicago Undergraduate Division of the University of Illinois conceived the idea of a "Committee of 1000 for A.G.I." in which less affluent members of the profession, who could not afford to join the Committee of 100, could

contribute $10 to A.G.I. The Board of Directors authorized the Executive Committee to form a "Committee of 1000 for A.G.I." for 1959. Such contributions would be for the year unless the individual wished to continue.

c. During the past year A.G.I. prepared and distributed more than 15,000 copies of a new career booklet "Shall I Study the Geological Sciences?" and published "Earth for the Layman" and a second edition of "Directory of Geological Information." Beginning in 1959, A.G.I. will publish "Geo-Science Abstracts" which will replace "Geological Abstracts," publication of which is being discontinued by G.S.A.

d. Following receipt of NSF grants totaling $140,000, a Russian Translation Center, managed by Dr. R. W. Fairbridge, has been set up just off the campus of Columbia University. Work is proceeding on translation of the Russian abstract journal, *Referativnyi Zhurnal*, the *International Geology Review*, and two books, Nalivkin's "Facies Studies," and Belousov's "Fundamental Problems in Tectonics." The *International Geology Review* is expected to appear in January, 1959; the two books about mid-1959. The translation project is described in some detail in the October, 1958, issue of *GeoTimes*.

8. *Report of the S.E.P.M. Representative to the A.G.I. Government Relations Committee* (*Norman S. Hinchey*).—Several members of the A.G.I. Government Relations Committee met on November 7, 1958, in St. Louis, Missouri. The new chairman was unavoidably prevented from being present and Robert C. Stephenson, executive director of A.G.I., presided informally in his absence.

Topics which were discussed briefly included: proposed rules for fossil collecting on federal lands, presented by S.V.P.; a proposed geophysical research institute in Hawaii; travel reimbursement for government scientists serving non-profit organizations as distinguished lecturers, etc.; a suggested proposal to found a minerals research institute; and licensing and registration.

9. *Report of the Joint Committee on Invertebrate Paleontology* (*Raymond C. Moore*).—Chief accomplishment on the Treatise project during 1958 has been completion of the volume on Trilobitomorpha (mainly trilobites) with an accompanying introduction to the phylum Arthropoda and description of the nontypical jointed-leg invertebrates classed as Protarthropoda. This volume (Part O) will contain approximately 570 pages and very numerous illustrations. It is the work of 18 contributing authors from six countries and because of complex division of the work for preparation of systematic descriptions, as well as the unsettled nature of numerous problems of classification, unusual difficulties have been encountered. Work now is finished except for offset printing and binding.

Prospectively the next published Treatise volume will be Part I (Mollusca 1), which is planned to include the chitons, scaphopods, and Paleozoic gastropods. Final editorial work on this unit is in progress and type setting is about to begin. Work also is actively under way to complete organization of Part Q (Arthropoda 3) on ostracodes and it is possible that at least one or two other units may be made ready for press during 1959. Unhappily, no definite statement yet can be made as to the probable time of publication of Part C (Foraminifera), even though it had been expected that this unit would have been completed before 1958. Major sections of the typescript have not yet come into hands of the editor, although some divisions have been completed long ago.

10. *Report of S.E.P.M. Representative on Council of A.A.A.S.* (*Robert B. Neuman*).—I attended the meeting in Washington, D. C., in December, 1958, as the S.E.P.M. member of the Council of the A.A.A.S. These conclaves are unique in this country in bringing together scientists (and science teachers) in many fields with the obvious danger of cross-fertilization. Thus the Section E program on the history of geology brought together science historians as well as geologists. Section L (History of Science) continued the theme with a program of papers on Darwin. Other programs with papers of special interest to me and my paleontological associates were given by the Society of Systematic Zoology (in Section F), and the Dentistry Section (a Symposium on calcification in Geological Systems) to name two. There were several others. This kind of program together with the broad educational aspects of A.A.A.S., and the fact that the A.A.A.S. is playing a large part in organ-

izing the International Oceanographic Congress in New York in September, 1959, (another example of its interdisciplinary functions) seem to me to warrant continued affiliation of the S.E.P.M. with the A.A.A.S.

11. *Report of the Permian Basin Section* (*Carl Ulvog*).—The fourth annual meeting will be held at the Desert Aire Motel in Alamogordo, New Mexico, on April 16, 1959. Registration for this meeting is scheduled to begin the afternoon of April 15. Mr. M. R. Stipp is general chairman. A most interesting technical session is being arranged under the supervision of Mr. R. F. Meyer, program chairman.

A field conference in the Sacramento Mountains will follow the business and technical meeting, being slated for April 17 and 18. Arrangements will be made for registering during the afternoon of April 15 and all day April 16, at the Desert Aire Motel, Alamogordo, New Mexico. The field conference is sponsored jointly by the S.E.P.M., Permian Basin Section, and the Roswell Geological Society. Chairmen are Carl Ulvog and Frank Packard. The field trip will be confined to the west slope of the Sacramentos and will be under the general leadership of Dr. Lloyd C. Pray.

Officers elected for 1958 were: J. P. D. Hull, Jr., President; Carl Ulvog, 1st Vice-President; M. Russell Stipp, 2nd Vice-President; Edward R. Kennedy, Secretary; and Roy Harris, Treasurer. Mr. Hull subsequently resigned from his position and Mr. Ulvog is completing his term. Since March 1, 1959, is the deadline for ballots to be returned, the 1959 executive committee cannot be named at this time.

The Midland group is planning a series of evening meetings, the first of which will be held on January 28. It is hoped that these meetings will arouse greater interest and activity in our organization. Membership is steadily increasing, having now reached a total of 433, of which 12 may be considered as residing completely outside of the Permian Basin Area.

12. *Report of the Gulf Coast Section* (*Marcus A. Hanna*).—The past year, 1957–58, under the Presidency of Jack Collie, continued the success of preceding years.

The Gulf Coast Section jointly with the Houston Geological Society held a field trip December 6 under the leadership of Fred Smith, Professor of geology at Texas A. & M. College. The field trip committee consisted of E. H. Rainwater, chairman, C. W. Stuckey, Jr., H. G. Schoenike, H. B. Stenzel, and L. J. Vittrup. It was assisted by many other individuals. The trip covered the "Upper and Middle Tertiary of Brazos River Valley, Texas." Although the weather was cold some 275 individuals made the one day trip. The field trip guide book is available through the Houston Geological Society.

The annual meeting of the section was held in Corpus Christi, Texas, October 27 through 29, 1958. The first day of the two-day Technical Session was a joint meeting with the Gulf Coast Association of Geological Societies. The second day, the section held its own technical session concurrently with the other meeting. Several interesting papers were presented.

The annual business meeting followed the technical session with President Jack Collie presiding. Reports of the officers and committee chairmen were presented. Accomplishments and anticipated activities of several projects were discussed.

President Collie thanked his officers and the members for their cooperation during the year. The incoming president talked a few moments after which the meeting adjourned.

Many of the members were a part of the group of near 100 which attended the field trip October 30 through November 1 in a study of "Sedimentology of South Texas."

13. *Report of the Pacific Section* (*Charles W. Cary*).—The Pacific Section has an active paid-up membership of 140, and a balance in the treasury of $1,948.66. President of the Section is Charles W. Cary and Secretary-Treasurer is Alvin A. Almgren.

This year, National and Pacific Section S.E.P.M. membership awards and subscriptions to both *Journals* were granted to eighteen students from various Pacific Coast Colleges and Universities. The faculty of the Paleontology or Geology Department of each school nominated the student to receive this award.

The monthly Biostratigraphy Seminar, sponsored jointly by the Pacific Section S.E.P.M. and the Bakersfield College, is in

progress. Eight papers by distinguished research workers from the West Coast, covering the field of stratigraphy, paleontology, and ecology, are being presented. Mr. Stan Carlson is chairman, and the average attendance at the meetings is approximately fifty.

The S.E.P.M. Pacific Section sponsored their annual dinner meeting and field trip on April 24 and 25. Dr. Earl Brabb is chairman of the event and will be assisted by Dr. Weldon Rau. The Geology and Paleontology of exposures in the vicinity of Boulder Creek, Santa Cruz Mountains, California, will be studied. Dr. Brabb will present a paper on the Stratigraphy of the Boulder Creek Area at the Friday evening dinner preceding the field trip.

The Pacific Section S.E.P.M. will again cooperate with the A.A.P.G. and S.E.G. in putting on the Thirty-Sixth Annual Fall Meeting at Los Angeles on November 12 and 13. A two-day technical session and dinner meeting are being planned by Dr. Weldon Rau, program chairman.

A dinner dance will be held in December which is co-sponsored by the S.E.P.M.—A.A.P.G.—S.E.G. On the committee representing S.E.P.M. will be Richard L. Brooks.

14. *S.E.P.M. President's Report* (*Gordon Rittenhouse*).—The financial condition of the Society continues to improve. The General Fund showed a profit of $4,274.61 as compared with a profit of $907.46 in 1957 and a loss of $637.17 in 1956. The Publications Fund showed a profit of $1,608.85 as compared with $4,101.77 in 1957 and $1,860.88 in 1956. These figures are not all "cash," since inventory of our publications and other factors are taken into consideration in arriving at these figures.

The improved status of the General Fund is due in part to the increase in dues that became effective in 1958 and in part of lower than anticipated costs of publication of the Society's two journals. The editors of the two journals are to be highly commended for their efforts in holding down costs, as well as for continuing their usual efficient handling of the two publications. The smaller profit on the Publications Fund was due partly to the *Journal of Sedimentary Index* remaining a "loss" item and partly to much smaller income from sales of "Carbonate Deposition" which was published in 1957.

Membership in the Society has increased only slightly during the past year and numbered 1456 on December 31, 1958, as compared with 1413 on December 31, 1957. Because of the adverse economic situation during the year, no special effort toward increasing membership was made. A need for such efforts has been discussed with President-Elect Ellison who has acted to appoint a Membership Committee.

The Research Committee under the chairmanship of Grover Murray organized a symposium on "Concepts of Stratigraphic Classification and Correlation" for presentation at the Dallas meeting. The subject "Relationship of Paleontology and Mineralogy to Polar Wandering and Continental Drift" was selected for the symposium at the 1960 meeting at Atlantic City. Arrangements for this program, which is being organized under the direction of Arthur Munyan, vice-chairman, are largely completed. The 1958 symposium entitled "Silica in Sediments" is appearing early in 1959 as a S.E.P.M. Special Publication.

Because there is a very limited pool of the members eligible for nomination for president, a special committee composed of H. B. Stenzel, F. J. Pettijohn, and R. R. Shrock, chairman, was appointed to consider the whole problem of how and from whom to choose the president. The recommendations of this committee will be presented to the council and members for consideration.

I wish to extend my sincerest gratitude to the many members of the Society who have served as officers, editors, representatives, and committee members during my term of office.

It was moved, seconded, and carried that the By-Laws be changed to read as follows:

Article III, Section 1. Nominations for officers shall be made in the following manner. Prior to September 1 of each year, the president shall designate a nominating committee to consist of not less than five members none of whom shall be members of the council, instructing this committee to submit two nominations for president, vice-president, and secretary-treasurer, and nominations for editors of the two Journals,

these nominations to be in the secretary's hands before September 15. If desired, this committee may nominate two slates of candidates for editor of one or both of the Journals.

Article VIII, Section 1. The president and the past-president shall be directors of the American Geological Institute, the past president being the senior director. They shall represent the Society on said Institute. The term of office as directors shall begin at the fall meeting of the American Geological Institute following assumption of their office and shall terminate two years later; provided that this provision in no way extends their terms of office as members of the council of the Society.

It was moved, seconded, and carried that a referendum vote (in the form of a mailed ballot) be taken to determine whether the Society desires one or two slates of officers.

The meeting was turned over to incoming President Samuel P. Ellison, Jr., who called for a report of the Resolutions Committee.

The Resolutions Committee, composed of F. T. Connolly (chairman), Lynn Jacobsen, and J. Robert Moore, III, presents the following "Resolutions of Thanks."

BE IT RESOLVED THAT in behalf of the Society we extend an expression of our sincere thanks to the following:

TO WILLIAM M. FURNISH, technical program chairman, for his general supervision and handling of the technical program;

TO JAMES E. BROOKS, S.E.P.M. vice-chairman, for his capable attention to the many details of the meeting;

TO GROVER E. MURRAY, chairman of the Research Committee, together with W. C. BELL and L. L. SLOSS, for preparing the Research Symposium, "Concepts of Stratigraphic Classification and Correlation";

TO JULES BRAUNSTEIN and ALFRED G. FISCHER for arranging the papers on mineralogy and sedimentary petrology, and on paleontology and stratigraphy;

TO W. DOW HAMM, general chairman, WILLIAM B. HEROY, general vice-chairman, ROBERT E. RETTGER, A.A.P.G. program chairman, and to the chairmen and members of all the convention sub-committees, for their efforts in the organization of the Dallas convention;

TO THE EXECUTIVE COMMITTEE of the A.A.P.G., for appropirating $2,000.00 as office rent for the Society Headquarters at Tulsa;

TO ROBERT H. DOTT, for his continued guidance as Business Manger of the S.E.P.M.;

TO OUR EDITORS—M. L. THOMPSON, CHARLES W. COLLINSON, and JACK L. HOUGH, for their untiring efforts in the time-consuming job of editing our publications, the *Journal of Paleontology* and the *Journal of Sedimentary Petrology*;

TO ROBERT R. SHROCK and BARBARA H. BLOOM for the preparation of the Index to the *Journal of Sedimentary Petrology* and to JACK L. HOUGH for editing that volume;

TO H. A. IRELAND for editing our Special Publication Number 7, *Silica in Sediments*;

TO DANIEL A. BUSCH and PHILIP H. SCRUTON, for designing the book plate to be used for the award for the Best Paper Presented at the Convention;

AND TO THE STATLER HOTEL, for providing excellent convention headquarters facilties.

The meeting adjourned at 2:15 P.M.

CONSTITUTION AND BY-LAWS

(AMENDED, 1958 AND 1959)

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

A DIVISION OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

CONSTITUTION

ARTICLE I. NAME

The Society shall be known as the Society of Economic Paleontologists and Mineralogists.

ARTICLE II. OBJECT

The object of the Society shall be to promote the science of stratigraphy through research in paleontology and sedimentary petrology, especially as these relate to development of knowledge of the geology of petroleum.

ARTICLE III. MEMBERSHIP

1. The Society shall be composed of active members, associate members, honorary members, correspondents, and patrons.

2. Active members shall be persons engaged in paleontologic, petrographic, or stratigraphic studies as applied to the geology of petroleum and who have been duly elected active members, juniors, or associates in The American Association of Petroleum Geologists.

Active and honorary members only shall be known as members.

3. Associate members shall be known as associates. Any person engaged in paleontologic, petrologic, or stratigraphic studies that have application to the geology of petroleum is eligible for associate membership. Associates shall enjoy all the privileges of membership in the Society, save that they shall not hold office, sign applications for membership, or vote.

4. Honorary members shall be persons of distinguished achievement whose contributions to paleontology, petrology, and stratigraphy have an application to the geology of petroleum.

5. Correspondents shall be persons not resident in North America who have made distinctive contributions to paleontology, petrology, and stratigraphy that have application to the geology of petroleum.

6. Patrons shall be persons who have bestowed important favors on the Society.

ARTICLE IV. OFFICERS

1. Executive authority of the Society is vested in a council consisting of six members, duly elected officers, as follows: president, vice-president, secretary-treasurer, the past-president, and the editor of each of the two Journals. The chairman and the vice-chairman of the Research Committee and the presidents of Regional Sections shall be non-voting members of the council.

2. The president shall discharge the usual duties of a presiding officer at all meetings of the Society and council.

3. The vice-president shall assume the duties of the president in case of his absence.

In the event of the absence from the meetings of both president and vice-president, the duties of presiding officer shall fall upon one of the other members of the council in the following order: past-president, secretary-treasurer.

4. The secretary-treasurer shall keep records of the proceedings of the Society, and a complete list of the membership. He shall attend to the preparation and mailing of notices and other materials required in the business of the Society. The secretary-treasurer shall have custody of all funds of the Society, and shall keep a detailed account of receipts and disbursements.

5. The council shall consider all nominations for membership and pass on the qualifications of the applicants; may elect honorary members, correspondents, and patrons; shall have control and management of the affairs and funds of the Society; shall determine the manner of publication and pass on the material presented for publication; and shall designate the place of the annual meeting. In the event of a tie vote among the voting council, the president, vice-president, and secretary-treasurer's votes shall prevail. The council is empowered to establish a business headquarters for the Society and to

employ such persons as are needed to conduct the business of the Society.

6. Elections shall be held annually to select a president, vice-president, secretary-treasurer, and the editors.

ARTICLE V. MEETINGS

1. The Society shall hold at least one stated meeting a year, which shall be designated as the annual meeting. The time and place of the annual meeting shall be designated by the council, but in general, it shall be held in connection with the annual meeting of The American Association of Petroleum Geologists.

2. The annual meeting shall be devoted to the reading and discussion of scientific papers, to the transaction of Society business, and other appropriate functions.

3. The program for the annual meeting shall be arranged by the council, or under its direction.

ARTICLE VI. SECTIONS

Local sections of the Society may be established according to provisions of the by-laws.

ARTICLE VII. AMENDMENTS

The constitution may be amended by a two-thirds vote of returned mail ballots received by the secretary-treasurer sixty days after proposal of amendments with provision for vote is mailed to the membership; provided that the proposed amendment has been signed by at least twenty members, and provided further that the proposed amendment must first have the approval of the council and the executive committee of The American Association of Petroleum Geologists.

BY-LAWS

ARTICLE I. DUES

1. The fiscal year of the Society shall correspond with the calendar year.

2. The annual dues of members and associates of the Society who desire only the *Journal of Paleontology* shall be ten dollars ($10.00). The annual dues of members and associates who desire only the *Journal of Sedimentary Petrology* shall be seven dollars ($7.00). Members and associates may receive both Journals by the payment of seventeen dollars ($17.00). Members of the Society who are also members of the Paleontological Society and receive the *Journal of Paleontology* through the latter Society, may retain membership in the Society of Economic Paleontologists and Mineralogists by the payment of two dollars ($2.00) per year dues. The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before September 1 of each year, stating the amount of annual dues and the penalty and conditions for default of payment. Members and associates who shall fail to pay their annual dues by January 1 shall not receive further copies of either Journal, nor shall they be privileged to buy Society publications at special discounts made to the membership, until such arrears are met.

3. The council may from time to time elect as honorary members, correspondents, and patrons, candidates who have been nominated by a majority vote of the research committee. A vote of four members of the council shall be required for election. Honorary members, correspondents, and patrons shall not be required to pay annual dues.

ARTICLE II. DUTIES AND PRIVILEGES OF MEMBERS

1. Members and associate members dropped for non-payment of dues may apply to the council for reinstatement, and, provided settlement is made of any outstanding indebtedness for publications and other charges approved by the council, may be reinstated by vote of four members of the council.

2. Members shall be eligible to receive publications of the Society at special subscription rates as authorized by the council or as provided in these by-laws.

3. The council is authorized to transmit without charge such publications as it may direct to honorary members, correspondents, and patrons.

4. Only active and honorary members shall have the right to vote in electing officers and in transacting the business of the Society.

ARTICLE III. OFFICERS

1. Nominations for officers shall be made in the following manner. Prior to September 1 of each year, the president shall designate a nominating committee to consist of not less than five members none of whom shall be members of the council, instructing this committee to submit two nominations for president, vice-president, and secretary-treasurer, and nominations for editors of the two *Journals*, these nominations to be in the secretary's hands before September 15. If desired, this committee may nominate two slates of candidates for editor of one or both of the *Journals*.

2. Ballots containing the nominations for officers, alphabetically arranged under each office, shall be prepared by the secretary-treasurer and mailed to each member of the Society on or before October 1. Neither the ballot nor the enclosing envelope need contain the name of the voting member, but an outer envelope that contains the sealed ballot must bear the name of the voting member. The returned ballots received by the secretary-treasurer on or before December 1 shall be counted by him, and if requested, shall be submitted to recount by the council. A plurality of the votes received for any office constitutes election.

3. If, after his election by the regular ballot, the president shall not be able to discharge the duties of his office, because of death or resignation, the duly elected vice-president shall then assume the duties and title of president with all of the authority vested in him by the Constitution. In the event the vice-president shall not be able to assume said duties, then the succession shall be in the following order: past-president, secretary-treasurer. If none of the above mentioned members of the council shall be able to assume the office of the president, then a special election shall be held in which at least two qualified members, nominated by the council, shall be voted upon by the membership by means of a special mailed ballot. Any vacancies in the normally constituted council caused by such succession or for any other reason may be filled with a temporary appointment by the council.

4. Nominees for the office of president shall be active members in good standing, who shall have served (or may be serving concurrently at the time of nomination) as vice-president, secretary-treasurer, chairman of the Research Committee, or editor of one of the Society's official publications.

5. The vice-president shall be the officer of the council responsible for arrangements for the annual meeting, including selection of program chairmen, and shall keep in close contract with the Research Committee and others concerning technical papers and symposia to be presented.

ARTICLE IV. PUBLICATIONS

1. There shall be two editors, one for the *Journal of Paleontology* and one for the *Journal of Sedimentary Petrology*. The editors shall be in charge of editorial business of their respective Journals. Each shall submit an annual report of such business, shall have authority to solicit papers and material for such Journals, and may appoint associate or co-editors.

2. The *Journal of Paleontology* and the *Journal of Sedimentary Petrology* are designated as official publications of the Society. The council is not authorized to initiate and publish other periodicals.

3. A publication fund may be established consisting of an assignment of a portion of dues as designated by the council, and such donations as are specifically made for that purpose. The council is authorized to provide special publications from this fund as may be deemed desirable, and to fix terms for sale or other distribution of these publications.

ARTICLE V. FINANCIAL METHODS

1. No financial obligations shall be contracted without express sanction of the Society or council, but all ordinary incidental running expenses have sanction without special action.

2. Statements of accounts charged to the Society, other than miscellaneous running expenses, shall be approved by the president before the secretary-treasurer pays the amount out of funds of the Society not otherwise appropriated, and the receipted bill shall be held as the secretary-treasurer's voucher.

3. The secretary-treasurer shall have charge of the financial affairs of the Society and shall annually submit reports as secre-

tary-treasurer covering the fiscal year. He shall receive all funds of the Society, and, under the direction of the council, shall disburse all funds of the Society. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Society funds. The amounts of such bonds shall be set by the council and the expense shall be borne by the Society. The funds of the Society shall be disbursed by check as authorized by the council.

ARTICLE VI. BUSINESS REPRESENTATIVES

The president and the secretary-treasurer of the Society shall act as business representatives of the Society in the business committee of The American Association of Petroleum Geologists. These representatives shall conduct such business with the executive committee of the Association as is of mutual interest to the Society and the Association in the interims between the annual meetings of the Society and the Association. Approval of the action of these representatives on the part of the Society during any year is reserved to the council in session at the annual meeting at the close of that year. Questions remaining unsettled between the representatives of the Society and the executive committee of the Association shall be considered in a joint meeting of the council of the Society or its authorized representatives and the executive committee of the Association at the annual meeting of the Association at the close of the interim period during which such questions have arisen.

ARTICLE VII. SECTIONS

1. The establishment of local sections of the Society may be authorized by unanimous vote of the council approving a petition for such establishment signed by ten members of the Society. Such local sections may elect officers, conduct meetings, and engage in other scientific activities.

2. The council is authorized and directed to withdraw the charter of any established local section if there is evidence that it has become inactive.

ARTICLE VIII. DIRECTORS OF AMERICAN GEOLOGICAL INSTITUTE

1. The president and the past-president shall be directors of the American Geological Institute, the past-president being the senior director. They shall represent the Society on said Institute. The term of office as directors shall begin at the fall meeting of the American Geological Institute following assumption of their office and shall terminate two years later; provided that this provision in no way extends their terms of office as members of the council of the Society.

2. In the event of a vacancy by resignation, death, or other causes among the two directors who represent the Society on said Institute, the president of the Society shall nominate a director from the ranks of active members of the Society, and this director shall complete the unexpired term.

ARTICLE IX. REPRESENTATIVE ON NATIONAL RESEARCH COUNCIL

At the expiration of each three-year term, the president shall appoint a representative on the National Research Council to serve for a term of three years.

ARTICLE X. RESEARCH COMMITTEE

1. The objectives and duties of the Research Committee shall be to foster and encourage research; to advise the Society and council on research activities which may concern the Society, or which may be recommended or initiated under its sponsorship; to develop a symposium for the annual meeting if so requested; to select recipients for Best Paper Awards each year for each Journal; to nominate candidates for honorary members, correspondents, and patrons; and to deal with any other matters referred to it from time to time by the president or the council.

2. The activities of the Committee shall be directed by a chairman and a vice-chairman, to be appointed by the president, with the approval of the council, from the active members of the Committee. The term of the appointment of the chairman shall be one year. The vice-chairman will normally succeed the chairman the following year. In the event either of these offices is vacated for any reason, the council shall appoint a

qualified replacement for the unexpired term.

3. Membership of the Committee shall be appointed by the president from members and associates of the Society. The Committee shall consist of fourteen members, but this total may be changed at the discretion of the council. Two committee members, preferably one paleontologist and one mineralogist, shall be chosen from each of several geographic regions to be selected by the council. In addition, advisory members may be appointed from foreign areas. The terms of appointment of members and advisory members shall be for three years. Appointments shall be staggered, with the junior member from any region serving at least one year with the senior member from that region. If vacancies develop on the Committee the president shall make suitable appointments for the unexpired term.

ARTICLE XI. PUBLICATIONS COMMITTEE

1. The membership of this committee shall consist of five members, including a chairman, three other members, and the chairman of the Research Committee as an ex-officio member. The tenure of office of the chairman and members shall be two years. Membership of the committee shall be appointed by the president from members and associates of the Society.

2. The duties of the Publications Committee shall be to recommend to the council manuscripts or symposia which merit consideration as S.E.P.M. special publications. The Publications Committee shall further recommend type of reproduction, number of copies, and cost figures of manuscripts or symposia.

3. Upon approval of the council, this committee, with the appropriate Society editor or editors, shall edit (or have edited), and publish these manuscripts or symposia.

4. The activities of this committee will include recommending to the council suggestions for improving the quality of our Society *Journals* consistent with the budgeted monies allotted for publication.

ARTICLE XII. AMENDMENTS

The by-laws may be amended at any annual business meeting by two-thirds vote of the members present, or by mail ballot sent to the members, in which case two-thirds of the returned ballots received in sixty days after mailing must approve the amendment in order to make it effective. Any proposed changes to the by-laws must first have the approval of the council.

NOMINEES FOR S.E.P.M. PRESIDENT, 1960–1961

WILLIAM M. FURNISH, JR.

Professor of Geology, State University of Iowa, Iowa City, Iowa
Born, August 17, 1912, Tipton, Iowa

Academic Training

State University of Iowa, B.A., '34; M.S., '35; Ph.D., '38

Experience

1939	U. S. Geol. Survey, jr. geol.
1938–40	State University of Iowa, Iowa City, Iowa, res. assoc.
1940–41	Oklahoma A. & M. College (Oklahoma State University), Stillwater, Oklahoma, instructor
1941–44	Shell Oil Co., Tyler, Texas, geol.
1944–46	R. Lacy Inc., Longview, Texas, geol.
1946	Union Producing Co., Tyler, Texas, geol.
1947–49	Creole Petroleum Corp., Maracaibo, Venezuela, dist. geol.
1949–53	Arabian-American Oil Co., Dhahran, Saudi Arabia, div. geol.
1953–	State University of Iowa, Iowa City, Iowa, assoc. prof. and prof. of geol.

Publications.—Paleontological studies on cephalopods and conodonts

Professional Affiliations (*National*)

Geological Society of America, fellow
American Association of Petroleum Geologists, member
Association of Geology Teachers, member
Sigma Xi

S.E.P.M. Activity (Associate, '50; Member, '55)

1955–57	Editor—*Journal of Paleontology* and member of council
1957–58	Chairman, Special Publications Committee
1958–59	Vice-President

WILLIAM J. PLUMLEY

Division Supervisor, Geologic Research, California Research Corporation, La Habra, California
Born, January 9, 1918, Rockford, Illinois

Academic Training

Univ. of Chicago, B.S., '40; M.S., '41; Prof. Certificate in Meteorology, '42; Ph.D., '48

Experience

1941	Carter Oil Co., geol. trainee
1942–46	U. S. Army Air Force, meteorology
1946	Carter Oil Co., geol.
1948–	California Research Corporation, La Habra, Calif., res. geol.

Publications.—Sediment transport, carbonate rock petrology, sediment textural analysis

Professional Affiliations (*National*)

American Association of Petroleum Geologists, member

S.E.P.M. Activity (Member, '55)

1956–58	Research Committee Member
1957	Co-chairman of Symposium on Sedimentary Geochemistry
1959–60	Vice-President

NOMINEES FOR S.E.P.M. VICE-PRESIDENT, 1960–61

W. D. KELLER

Professor of Geology, University of Missouri, Columbia, Missouri
Born, March 13, 1900, North Kansas City, Missouri

Academic Training

Univ. of Missouri, B.A., '25
Missouri School of Mines, B.S., '30
Harvard University, M.A., '31
Univ. of Missouri, Ph.D., '33

Experience

1926	Empire Gas and Oil, exploration geology
1926–29	Univ. of Missouri, instructor
1929–30	A. P. Green Fire Brick Co., ceramic technologist
1932–	Univ. of Missouri, assistant, associate, professor
1945	U. S. Army, Florence, Italy, instructor

Publications.—Sedimentation, fire clay, geochemistry

Professional Affiliations (National)

Geological Society of America, fellow
Mineralogical Society of America, fellow
American Association for the Advancement of Science, fellow
American Institute of Mining and Metallurgical Engineers, member
American Association of Petroleum Geologists, member
Geochemical Society, member

S.E.P.M. Activity (Member, '48)

Program Chairman, 1951
Chairman of Committee to Select Best Paper at 1958 Convention

LAURENCE L. SLOSS

Professor of Geology, Northwestern University, Evanston, Illinois
Born, August 26, 1913, Mountain View, California

Academic Training

Stanford University, B.A., '34
University of Chicago, Ph.D., '37

Experience

1937–46	Montana School of Mines (instructor and assistant professor), and Montana Bureau of Mines and Geology (geologist)
1947–	Northwestern University, assistant, associate, professor
1942–50	(Summers) Carter Oil Co., Phillips Petr. Co., U.S.G.S., structure and stratigraphy, Rocky Mountain Area

Publications.—Stratigraphy and sedimentary petrology

Professional Affiliations (National)

American Association of Petroleum Geologists, member
Geological Society of America, fellow
Paleontological Society, member
American Geophysical Union, member
American Association for the Advancement of Science, fellow

S.E.P.M. Activity

1950	Program Chairman
1954	Nominating Committee
1955–57	Research Committee Member
1959	Co-Chairman Research Committee Symposium

NOMINEES FOR S.E.P.M. SECRETARY-TREASURER, 1960–1961

LEWIS M. CLINE

Professor of Geology and Geological Research, University of Wisconsin, Madison, Wis.
Born, September 25, 1909, Duncan, Oklahoma

Academic Training

University of Tulsa, B.S., '31
University of Iowa, M.S., '34; Ph.D., '35

Experience

1935–36	Texas A. and M. College, College Station, Tex., instructor
1936–42	Iowa State College, Ames, Iowa, assistant professor
1935–42	(Summers) Iowa Geological Survey, geologist
1942–45	Standard Oil Co. of Texas, Houston, Tex., district geologist
1946–	University of Wisconsin, Madison, Wis., professor

Publications.—Paleontology and stratigraphy

Professional Affiliations (National)

Geological Society of America, fellow
American Association of Petroleum Geologists, member
Paleontological Society of America, member

S.E.P.M. Activity (Member, '55)

1957–60 Research Committee Member

JOHN IMBRIE

Professor of Geology and Geological Research, Columbia University, New York, N. Y.
Born, July 4, 1925, Penn Yan, New York

Academic Training

Princeton University, B.A., '48
Yale University, M.S., '50; Ph.D., '51

Experience

1951–52	University of Kansas, Lawrence, Kans., research and teaching
1952–57	State Geological Survey, Lawrence, Kansas, (part time)
1952–	Columbia University, New York, N. Y., prof. of geol. and geol. res.

Publications.—Systematic paleontology, biometrics, general paleontology, biostratigraphy, shoal-water geology of Bahamas

Professional Affiliations (National)

Geological Society of America, member
American Association of Petroleum Geologists, member
Society of Systematic Zoologists, member
Paleontological Society, member
Sigma Xi

S.E.P.M. Activity (Associate, '52; Member, '54)

Participation in various programs, including the Symposium on Geochemistry of Sediments, and the 1954 Symposium on Fauna and Facies
1959–60 Secretary-Treasurer

NEW OFFICERS OF PERMIAN BASIN SECTION

President: CARL ULVOG, Sunray Mid-Continent, Midland, Texas
First Vice-President: THOMAS HAMBLETON, Texaco, Midland, Texas
Second Vice-President: JOHN P. BRAND, Texas Technological College, Lubbock, Texas
Secretary: RAYMOND W. RALL, Tennessee Gas and Oil, Midland, Texas
Treasurer: CHARLES A. REINKE, JR., Magnolia, Midland, Texas
Past-President William A. Waldschmidt continues to serve in that capacity on the executive committee.

ANNOUNCEMENTS

S.E.P.M. PROGRAM FOR ATLANTIC CITY MEETING

APRIL 25–28, 1960

The Society of Economic Paleontologists and Mineralogists is planning a program for the Atlantic City 1960 meeting which will consist of the following:

1. A joint session with the A.A.P.G.
2. A session of volunteered papers on paleontology and stratigraphy, with Paul Tasch, University of Wichita, Wichita, Kansas, as Chairman.
3. A session of volunteered papers on sedimentary mineralogy and petrology and sedimentology, with A. L. Kidwell, Jersey Production Research Corporation, Tulsa, Oklahoma, as Chairman.
4. A symposium entitled "The Paleontological and Mineralogical Evidence for Polar Wandering and Continental Drift" followed by an evening symposium panel discussion. A. C. Munyan, Sohio Petroleum Company, P. O. Box 2558, Billings, Montana, is Chairman.

All persons interested in submitting papers for this program or who have suggestions for the symposium should write directly to the Chairman of the particular sesssion.

October 1 is the deadline for the submission of abstracts and papers for any part of the program. We will appreciate your cooperation and aid in helping us organize and present an outstanding program.

W. J. PLUMLEY
Vice-President, S.E.P.M.
Chairman, Technical Program

Special Publication No. 5 of

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

Box 979, Tulsa 1, Oklahoma

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